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Effects of Clothing on Human Decomposition and Deterioration of Associated Yarns

Shawn Elizabeth Cahoon
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To the Graduate Council:

I am submitting herewith a thesis written by Shawn Elizabeth Cahoon entitled "Effects of Clothing on Human Decomposition and Deterioration of Associated Yarns." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Anthropology.

William Bass, Major Professor

We have read this thesis and recommend its acceptance:

Richard Jantz, Randall Bressee

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

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EFFECTS OF CLOTHING ON HUMAN DECOMPOSITION AND DETERIORATION OF ASSOCIATED YARNS

A Thesis

Presented for the

Master of Arts

Degree

The University of Tennessee, Knoxville

Shawn Elizabeth Cahoon

May, 1992

DEDICATION

This thesis is dedicated to my parents

Robert Leroy Cahoon

and

Jacqueline Powell Cahoon

for their love and unflagging support

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Deepest thanks to the members of my committee, Dr. William Bass, Dr. Richard Jantz, and Dr. Randall Bressee, for their extraordinary patience and assistance.

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ABSTRACT

This study focuses on how a single layer of clothing affects human decomposition, and if human decomposition has a noticeable affect on clothing materials. Two cadavers were placed at the Anthropological Research Facility in Knoxville, TN on January 16, 1991. One was clothed, the other was nude. Seven different types of yarns were attached to the inside of the clothing on the experimental subject, and another set of these yarns was anchored to the base of nearby tree to serve as a control sample set.

Cadavers were monitored as they decomposed, and insect activity was observed, from January 16, 1991 until May 4, 1991. The National Weather Service provided daily high and low temperatures. Yarn samples were collected from January 16, 1991 until November 5, 1991 and examined visually, and fibers from the yarns were examined microscopically for mechanical/structural deterioration, and breaking strengths were measured.

The clothed cadaver (EXP) decomposed more quickly than the nude cadaver (CTL) did. EXP reached bloating and active decay almost twice as quickly as did CTL, probably because the garment facilitated the growth and development of carrion insects which are responsible for much of the destruction of the remains.

Fibers from experimental and control yarns showed little or no structural or mechanical damage microscopically or visually. Breaking strength tests indicated that the yarns responded differentially to human

decomposition. However, larger sample sizes and a longer period of research will offer clearer answers.

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CHAPTER I.

INTRODUCTION

Forensic anthropology is the application of the concepts and techniques of physical anthropology to medicolegal problems. Skeletal and badly decomposed remains as well as those badly damaged by fire pose an identification problem for police and other investigators. Anthropologists assist in determining if the remains are human, if more than one individual is represented, and the age, sex, race, stature, distinguishing or unique traits (i.e. congenital defects such as cleft palate; degenerative changes such as osteoarthritis; traumatic damage such as healed fractures; nutritional defects such as dental hypoplasia), and dental features of the individual(s) (Stewart, 1948). Such assistance offers a better chance of establishing the identity of the individual.

In addition to identifying remains, forensic anthropologists have in the past few decades studied the processes and rates of decomposition. Knowing the process and patterns of decomposition which occur after death, how quickly or slowly they occur, and the variables which affect these rates and patterns, allows for a more accurate estimate of post-mortem interval. By estimating when death occurred, missing person records can be surveyed and compared to the remains. Also, in criminal investigations, the knowledge of when the death occurred may be crucial in convicting or acquitting a murder suspect. In other cases, such studies can assist in determining if remains are of

immediate forensic/medicolegal interest, or if they are archaeological, historic, or recent cemetery remains which have been exposed by vandalism or natural causes (Berryman et al, 1991).

At the Anthropology Research Facility in Knoxville, TN, under the direction of Dr. William Bass, researchers have studied decompositional rates, processes, and the variables affecting them since 1980. Human remains donated to scientific endeavors, unidentified, or unclaimed by next of kin, have been studied under a number of conditions to document the sequence of events and/or the time involved (Mann et al, 1990).

The majority of these studies have used nude cadavers. Clothing prohibits easy observation of the decomposition process and activity of animal and insect scavengers, and may also affect that activity. Clothing has therefore been a hindrance to documenting the basic processes of decomposition when human remains are exposed to various environmental conditions. However, because clothing is often associated with forensic remains, it is important to study how clothing may affect the process. Also, in those case histories in which clothing associated with remains has been noted, the clothing (or fragments thereof) is often present well into the skeletonized stage. Clothing in such circumstances may exhibit a pattern of deterioration different from that of clothing suffering deterioration due solely to environmental conditions.

A few researchers have looked at the deterioration of materials associated with post-mortem processes (Morse et al, 1984; Morse and Dailey, 1985). However, none of these studies involved the effects of long term human decomposition on the structure and deterioration of various fabrics. It is important to understand how clothing affects decomposition, and how decomposition in turn may affect how various fibers deteriorate. Clothing may have an effect on the pattern of decomposition which could cause confusion if criteria developed for unclothed individuals are applied to clothed individuals, and fibers may be misidentified if decomposition has a sufficient effect on them.

This study examined both of these aspects. Two cadavers, one clothed and one nude, were followed at the Anthropology Research Facility from January 16, 1991 to May 4, 1991 to compare the process and pattern of decomposition. In addition, seven different yarn-types were exposed to non-human environmental factors (soil, mulch, rain, temperature, etc.) and to the clothed cadaver from January 16, 1991 to November 5, 1991. Deterioration of samples from the control experiment and the clothed cadaver was compared by means of visual and microscopic evaluation of fibers and by measuring the breaking strength of yarns. The results showed that a single layer of clothing accelerates human decomposition in later winter/early spring, and that different types of clothing

materials react differentially to association with human decomposition.

CHAPTER II

LITERATURE SURVEY

HISTORIC PERSPECTIVE

Anthropology is the study of humans -- their culture, artifacts, evolution, and ecological and biologic systems. Physical anthropologists focus on the studies of the human as a biological being. They look at the evolution of the human species from primate precursors, secular changes within and between human populations, bone histology and morphology, pathology in historic and archaeological populations as reflected in bones, and the disease processes of modern populations, such as osteoporosis (Campbell, 1985; Relethford, 1990; Wolpoff, 1980).

In studying such aspects, physical anthropologists have developed a very detailed understanding of the human skeletal system. Much of their work involves historic and archaeological populations, in which the bones may be all that is left of the actual humans under study. The earliest physical anthropologists were anatomists and physicians, already familiar with the human skeleton. As physical anthrolopolgy became more formal, human osteology (or the study of human bones) was intensely studied, and methods were developed to determine age, sex, race and stature from skeletal remains (Iscan, 1988). The Terry and Todd collections allowed for extensive fine tuning of these techniques by providing populations with known vital statistics for comparison with experimental results (Iscan,

1988). Research continues today on these techniques, and will indefinitely, as results from one segment of a population may not apply so well to other segments of that population, or to other populations all together.

In a forensic setting, skeletonized and/or burned remains may be all that is recovered. Without some knowlege of human skeletal systems, it would be impossible to identify the remains. In 1897, an anthropologist first testified in a criminal case requiring identification of skeletal remains (Snow, 1982). Since that time, physical anthropologists from the Smithsonian and other institutions have assisted various law enforcement organizations in identifying remains from criminal settings, and the armed services in identifying remains recovered from military conflicts (Snow, 1982). In the second half of the Twentieth Century, some physical anthropologists began to focus more and more on the applications of their training to forensic cases. By 1971, a Physical Anthropology Section had been formed in the American Academy of Forensic Sciences, which is considered "the world's premier organization in the forensic sciences" (Snow, 1982).

In many criminal cases, the remains which require identification are in a state of active or advanced decomposition. At this point, skin slippage has made it difficult if not impossible to collect fingerprints from the victim, and facial features may be disfigured to an extent that simple recognition is also impossible. Often,

such remains were handed over to physical/forensic anthropologists for removal of flesh and subsequent identification by skeletal parameters (pers. comm., Willey and Galloway, 1989). However, this involves the loss of potential evidence. Studies of the decomposition process are therefore important. Knowing what happens to a body after death can lead to recovery of evidence concerning the interval since death, whether the remains have been moved since the time of death, what variables affect the body and in what way, before the soft tissues are removed. It can give clues to the cause of death, to the manner of death, even to the identity of the person responsible for the death. Over the past few decades, forensic anthropologists and other forensic specialists have concerned themselves with these questions.

POST-MORTEM CHANGES AND THE PROCESS OF DECOMPOSITION

The basic process of decomposition is mediated by the differential rates of cell death and the activity of bacteria and other micro-organisms within the body. The sooner a body is recovered following death, the easier it is to determine the post-mortem interval. The processes of rigor mortis, algor mortis, and livor mortis all occur within hours following death. Rigor mortis, the stiffening of the body, proceeds from the death of cells within the body. Not all cells die at the time the human dies. A certain amount of oxygen and nutrients remains in the blood cells. Cell death throughout the body occurs as oxygen and

energy fail to be renewed and as waste products of cell metabolism fail to be transported away from the cells. As the cells die, rigor mortis sets in, beginning about 2 hours after death, peaking within another 10 hours, and disappearing in about 36 hours all together. As cell metabolism slows, body temperature drops. This cooling is algor mortis, and it proceeds at about 1 degree per hour (Baden and Hennessee, 1989). Livor mortis involves the settling of red blood cells out of blood plasma. The precipitate settles according to the laws of gravity. In about an hour, redness of the skin in the areas where the cells settle becomes apparent. Once the cells break down, the redness in the skin becomes permanent. This process takes about 8 hours (Baden and Hennessee, 1989). Based on this information, it is relatively easy to pinpoint the time of death within the first 36 hours. However, these processes, like all others, are affected by variables such as temperature, humidity, and drugs or poisons.

Decomposition occurs in an orderly manner. The researchers who have studied it have broken the various processes into stages, defined by the changes seen in the body. Different researchers have proposed various arrangements of these stages, based on the different environments where decomposition is studied, the types of carrion observed undergoing decomposition, and personal biases of the researchers (Galloway et al, 1989; Payne and King, 1968; Payne, 1965; Reed, 1958; Bornemissza, 1957).

In general, the basic sequence of stages is fresh, bloat, decay, and dry. Most of the variation comes from dividing the decay stage into two or more stages. While the setting of limits on each stage may be somewhat arbitrary, the pattern of decompositional events is not.

Rigor mortis, algor mortis, and livor mortis occur during the first or "fresh" stage of decomposition. During this period of time, most of the decompositional changes are internal. Cells break down, intestinal bacteria and other micro-organisms proliferate and are disseminated throughout the body (Cotton et al, 1987; Rodriguez and Bass, 1985; Payne, 1965; Bornemissza, 1957). Stiffness, lividity, and temperature changes occur, but generally the body remains intact. No skin slippage or hair mass loss is generally noted (Reed, 1958; Payne and King, 1968).

During the next stage, bloating, cellular autolysis and bacterial activity produce gases which have no means of escape from the body (Bornemissza, 1957). As they build up, they cause the chest and abdominal cavities to swell. Discoloration (gray, green, yellow, red, brown and black) spreads throughout the body (Galloway et al, 1989; Payne and King, 1968). Head and body hair loosen and often come away, and skin slippage occurs (Galloway et al, 1989). Bodily fluids seep from the eyes, nose, ears, mouth and anus (Payne, 1965). When the bloating stage reaches its peak, deflation will occur. The release of the pent up gases may occur explosively or gradually, through the

natural orifices of the body. Deflation marks the end of the bloating stage (Reed, 1958; Rodriguez and Bass, 1983; Galloway et al, 1989; Payne and King, 1968; Bornemissza, 1957).

During the decay stage, cracks appear in the skin; air gains entrance in this way and internal aerobic bacterial activity increases, thus speeding the internal decomposition (Reed, 1958; Rodriguez and Bass, 1983). Massive skin slippage occurs and soft tissues deteriorate, exposing bones (Galloway et al, 1989; Reed, 1958; Cotton et al, 1987). Body fluids seep away from the body, through natural orifices as well as through gaps in the soft tissues. Toward the end of this stage, molds, fungi, and bacterial colonies may occur on or around the remains (Bornemissza, 1957; Payne and King, 1968), and the remains begin to dry out. Hair which has fallen from the head usually forms a hair mat (Reed, 1958).

In general, the dry stage involves very little soft tissue associated with the bones (Galloway et al, 1989; Rodriguez and Bass, 1983; Reed, 1958; Bornemissza, 1957). This stage may last for several years, as the bones dry out, suffer damage from weathering and cracking, and undergo bleaching and exfoliation. Hair mats will slowly decompose (Galloway et al, 1989; Rodriguez and Bass, 1983; Reed, 1958; Bornemissza, 1957).

VARIABLES AFFECTING DECOMPOSITION

Types of studies and subjects used

The above discussion of decomposition, while highlighting the major events of the process, does not address the number of variables which affect it. In describing the decomposition process, the data have been collected from observations of actual forensic cases and from experiments designed to monitor decomposition from the time of death through the dry stage and beyond.

Data from forensic cases has been amassed from thousands of cases. In these "case studies," observation begins with the discovery of the body and time tables of decomposition are reconstructed. The observations include degree of decomposition, environmental conditions at the time of discovery (temperature, humidity, sun/shade exposure, exposure to water, precipitation), insect activity and other scavenger activity, and protection from the environment (buildings, burial, tarps, heavy clothing, etc.).

The diligent recording of these factors when studying case histories can result in the coordination of a great deal of information. The patterns of decomposition can be compiled and pieced together in this way. In addition, a large pool of case history studies from one area will document the environmental conditions and faunal and floral populations specific to that area.[1] The differences in conditions from one geographic region to another can

significantly affect the time it takes to reach the various stages of decomposition. They can also affect the basic processes of decomposition. Case studies have been submitted into the literature from: Washington state, south and west Indiana, Maryland, the Southwest, Washington DC, the Hawaiian Islands, the Cumberland Mountains, Chicago, and southern California (Lord, 1990); England (Easton, 1970); the Hawaiian Islands (Goff and Flynn, 1991; Goff et al, 1985); Arizona/Pima County (Galloway et al, 1989); Washington state (Haglund et al, 1990; Haglund et al, 1988; Haglund et al, 1989); Wales (Knight, 1971); Minnesota (Cotton et al, 1987); India (Kulshrestha and Chandra, 1987); and Indiana (Hawley et al, 1989).

Experimental studies follow and record decomposition starting with the time of death. Most of these studies involve the use of non-human subjects. Reed (1958) used dog carcasses and Payne (1965) and Payne and King (1968) used baby pigs. Other animals include rats, squirrels, rabbits (Micozzi, 1986), frogs, toads, mice, shrews, chipmunks, cats, chickens, and other birds (Payne, 1965). Other studies have used unspecified animal tissues such as fresh liver (Introna et al, 1991) or hamburger (Morse et al

[1] If time of death can be established in any given forensic case, climatological data for the post-mortem interval can be obtained from the nearest weather service station. This allows the decomposition rate to be synchronized with the local climatic conditions. Differences between climatology at the weather station and the death scene can be corrected by taking observations at the death scene and comparing them agains weather service data (Meeks and Andrews, 1990).

1984). Pigs are useful research subjects because their skin is similar to that of humans (lacking a thick fur coat), and because it is easy to obtain several specimens of uniform size (Payne, 1965). Older pigs have also been used, with body weights close to human body weights (Neil Haskell, pers. comm., 1989).

By following the decomposition of such subjects from the time of death and observing the effects of as many variables as possible, clear patterns of decomposition and insect activity have been documented. In conjunction with case history reports, they have contributed invaluable knowledge about the patterns seen and about environmental effects. By themselves, however, the studies on non-human subjects cannot be applied directly to human cases. Differences in size, weight, and body coverings (fur, feathers, skin) due to species differences have subtle effects that may make a difference in determining the interval since death or other aspects of the case.

Experiments involving the placement of human beings at the time of death and following them through skeletonization have been conducted for the past 11 years at the Anthropology Research Facility. This is the only known facility in which such research is conducted on human subjects. Such research is rare because of public concerns and distaste for such experiments and the political situations arising from this. The cadavers are obtained through the Tennessee State Medical Examiner's Office.

They have been donated to scientific endeavors, or are unidentified or unclaimed by their next of kin. These studies have followed human decomposition on various substrates (concrete slabs, wooded ground), on the surface and buried, throughout various seasons, etc. They have been observed in relation to environmental variables and scavenger activity, and these results have been added to the literature (Rodriguez and Bass, 1983; Rodriguez and Bass, 1985; Mann et al, 1990; Berryman et al, 1991).

Variables studied

The variables which affect decomposition are not easily separated into discrete categories. Instead, they are intricately connected. However, some have a much deeper impact on the process.

Insect activity has perhaps the greatest impact on the processes and duration of decomposition. Studies have indicated that remains exposed to insect activity decay much more quickly than do those which are protected from insects (Payne, 1965). In both human and non-human carrion placed on the surface at the time of death, insects in the form of flies arrived at the scene within minutes after placement and began depositing eggs (Payne, 1965; Gilbert and Bass, 1967; Payne and King, 1968; Reed, 1958; Catts, 1990). Eggs were deposited in and around the natural openings of the face (mouth, eyes, ears, nose), later at the anal and urogenital openings, and, if trauma was present, at the site of wounds (Lord, 1990; Goff and Catts,

1990; Gilbert and Bass, 1967; Payne, 1965; Rodriguez and Bass 1983; Reed, 1958; Smith, 1970).

Insect activity occurs in a series of waves or successions. The insect communities are composed of insects which feed directly on the carrion and their various predators. Specific families, genera and species of insects appear during each wave (Hall, 1990; Lord, 1990; Catts, 1990; Reed, 1958). Their presence or absence can give clues about location of the death scene (if the body has been moved since the time of death, there may be an interruption in the decomposition process and the insects involved) (Hall, 1990). By studying the growth and development of these insects, it is possible to determine the length of time they have been present, and this can lead to an estimate of the post-mortem interval. While there are differences in some species from one geographic region to another, and from one species of carrion to another, the overall patterns of succession and the same general type of insects have been observed. It is important to continue to study the differences for the different geographic regions, however; most estimates of post-mortem interval based on entomological information, for example, is usually based on a range of growth and development times from a number of insect species. This can narrow the range of the post-mortem interval significantly.

Insect activity significantly speeds the rate of

decomposition and appears to affect the process of decomposition. Insect activity includes deposition of eggs on the remains, and feeding on and digesting the carrion. The larvae (maggots) which hatch from the eggs previously deposited (maggots) occur in large numbers and grow rapidly. Maggot digestion does not occur internally; instead, external enzymes are produced which soften the surrounding carrion tissues and permit ingestion (pers. comm. Neil Haskell, 1991). As the maggots move thoughout the body and feed on it, they help to disseminate the intestinal bacteria and micro-organisms already present in the body more quickly and more widely than if there were no insect activity (Lord, 1990; Payne, 1965). The heat produced by this metabolic activity also assists in the decomposition processes (Catts, 1990; Payne, 1965).

Payne's study in 1965 compared the decomposition of pigs which were exposed to insects and those which were protected from insects. The pattern of decomposition when insects were present was much as was described in the earlier section of this chapter: bloating, rapid decomposition and destruction of soft tissues, and dry remnants shortly thereafter. His subjects were reduced to skeletal remains within a week during the summer. Those protected from insects, at the same time and in the same environmental conditions, exhibited a much different pattern of decomposition. Following the bloating stage, the pigs began to dehydrate and mummify. Soft tissues

survived, albeit as dried and leathery remnants. The process took several months.

Temperature is also extremely important. Bacterial activity is facilitated by high temperatures, while it is slowed or even arrested by lower temperatures. In addition, temperature has an effect on insect activity. Cold temperatures reduce insect activity and inhibit deposition of eggs and the growth and development of larvae (Mann et al, 1990; Reed, 1958; Lord, 1990; Goff and Catts, 1990; Galloway et al, 1989). Temperature variation may also have an effect. If the high and low temperature ranges within a short period are large, this can inhibit hatching, growth and development of the eggs and larvae (Hall, 1990; Goff, 1988; Reed, 1958). However, once the maggots are hatched and the maggot masses are firmly established, ambient (air) temperatures and temperature fluctuations will have little impact. The metabolic activity of maggot masses produces extremely high temperatures (Haskell, 1990; Mann et al, 1990). Even placement in morgue coolers has little effect on the maggot activity at this stage. In human decomposition in East Tennessee, high temperatures and heavy insect activity can skeletonize remains on the surface in two weeks to a month, while remains placed in the winter time may take several months to reach the same stage (Bass and Rodriguez, 1983; Mann et al, 1990).

Moisture affects the pattern of decomposition.

Humidity in combination with high temperature facilitates rapid decomposition. Dessication and mummification of remains occur in arid environments (Mann et al, 1990; Galloway et al, 1989). Conditions at high elevations cause extreme difficulties in determining the processes and post-mortem interval. Galloway et. al. (1989) have noted slower decomposition at higher elevations, due to increased precipitation, lower temperatures, and less insect activity. Catts (1990) indicates that the temperature extremes and the rapid freeze-thaw cycles result in rapid decomposition. Micozzi (1986) has noted that:

> "Freezing-thawing . . . accelerates rates of disarticulation . . . [it] diminished the capability of enteric organisms to grow and participate in postmortem putrefaction. The mechanical disruption of the tissues caused by freezing also weakens the skin, connective tissue, and joints, thus facilitating aerobic decay and skeletal disarticulation, and making internal organs more susceptible to invasion by foreign organisms and insects."

The apparent contradictions may be due to regional differences. Although Galloway et. al. and Catts are both describing conditions at high elevations with fluctuating temperatures, Galloway et. al. work in the Southwest, while Catts is based in Washington state and Micozzi in Washington, DC. Broad regional differences may affect conditions at high elevations.

Protection from insects and other environmental factors will affect the rate of decomposition. Burial inhibits insect access to the body, as do tightly sealed buildings

or containers (Rodriguez and Bass, 1985; Mann et al, 1990). In addition, ground temperatures are much less variable than ambient temperatures. Decomposition is much slower in buried remains than on those on the surface. Heavy clothing (many layers) or tarp or plastic coverings result in slower decomposition, because they increase the difficulty for establishing insect activity. In addition, they may interfere with non-insect scavenger activity (Galloway et al, 1989; Haglund et al, 1988; Mann et al, 1990). Immersion in water also slows decomposition (Cotton et al, 1987).

Non-insect scavengers (mammalian carnivores and rodents) will approach carrion at specific times during decomposition. Large carnivores such as canids (wolves, coyotes, domestic dogs) dismember and disarticulate remains in a predictable pattern (Willey and Snyder, 1989; Haglund et al, 1988; Haglund et al, 1989). Rodents prefer dry, usually long bones, which they will carry away from a site. They usually the bones for gnawing and wearing down their teeth, rather than for nutritional reasons (Haglund et al, 1988; Haglund et al, 1989).

Sun/shade exposure may have an effect on decomposition. Reed (1958) found that in direct sunlight there were lower insect populations but quicker insect succession, probably due to higher temperatures, while in wooded/shady areas there were more insects but slower succession and decomposition. Sunlight and any attendant drying were

noted to inhibit insect feeding and egg deposition (Willey and Snyder, 1989).

Trauma also has an effect on pattern and rate of decomposition. In non-traumatized individuals, insects approach natural body orifices. When trauma is present, they also approach the areas of wounding, enlarging these spots. Wounds provide additional sites for egg deposition and easy feeding (Mann et al, 1990).

CLOTHED REMAINS

Many case histories and experimental studies report the presence of various types of clothing associated with remains (Lord, 1990; Rodriguez and Bass, 1985). However, these studies rarely do more than comment on the presence of the clothing and caution that during entomological collections, clothing should be examined carefully. Mann et. al. (1990) suggest that clothing may speed decomposition by protecting maggots from the sunlight, while Galloway et. al. (1989) suggest that it may slow decomposition. Haglund et. al. (1988) also suggest that heavy clothing inhibits scavenger activity and the associated decomposition.

Studies at the Anthropology Research Facility generally involve nude cadavers. Again, in those cases where clothing is associated with remains, it is mentioned in passing only (Rodriguez and Bass, 1985). It has been important to study decompositional processes and rates as thoroughly as possible, and clothing makes it difficult to

make detailed observations without disturbing insect communities. Many forensic cases are nude, as well, so studies on clothed subjects are not necessary for those cases. For forensic cases which involve clothing, however, it is important that the responses of decomposition to clothing be documented; criteria from studies of nude cadavers should not be applied to clothed remains if clothing results in significant differences.

Approaching the problem from the other direction, it would be interesting to know how decomposition affects the associated fabrics. Clothing often survives well into the skeletal stage of decomposition (Lord, 1990; Rodriguez and Bass, 1985), and possibly beyond, depending on the type of fabric and the conditions with which it is associated. Differential deterioration of the fabrics may be able to give clues about the decomposition process or even post-mortem interval, which becomes very difficult once skeletonization is reached.

Very few studies have been published on the deterioration of fabrics, yarns, or fibers in a forensic setting. The majority of tests on fabrics, yarns and fibers which expose them to environmental conditions are concerned with their abilities to hold up to normal wear and tear as clothing. Studies have focused on exposure to sunlight, water, temperature ranges, fire, detergents, etc. (1990, ASTM). Morse et. al. (1984) studied several different materials commonly found associated with death

scenes: clothing-quality fabrics, shoe and wallet leather, and various types of paper. These materials were buried in trenches and dug up at regular intervals for testing. For the most part these materials were buried by themselves. In one experiment, different materials were associated with decomposing hamburger. However, only results of fabrics buried alone in trenches (plus those controls placed on the surface) are reported in the literature (Morse et al, 1984; Morse and Dailey, 1985).

Monahan and Harding (1990) examined how various fabrics respond to cuts and tears from different cutting instruments (blunt to serrated to sharp knives and other items frequently used as weapons in forensic cases), exposure to blood, and subsequent washing. The results indicated differential types of damage depending on the weave/knit of the fabric and the type of weapon used, and the subsequent exposure to blood, continued wear, and washing and drying. Cox (1990) looked at bloodstains and the ability to identify them following washing. However, there appear to be no studies in which fabrics, yarns or fibers are associated with body fluids on a long term basis or with extended decomposition.

TEXTILES

Textiles are classified by their structure. The primary divisions are natural and man-made, which are then divided by whether they are cellulosic and non-cellulosic. Cellulosic fibers are made of cellulose base products such

as wood pulp, while non-cellulosic fibers may be composed of animal proteins (for natural fibers) or products synthesized from oil or coal constituents (for man-made fibers). Natural cellulosic fibers include cotton, flax, and jute, while natural non-cellulosic fibers include wool and silk. Acetate is a man-made modified cellulosic fiber; nylon, polyester and acrylic are all examples of man-made non-cellulosic fibers (Joseph, 1977). The fibers or filaments are spun into yarns, which are then woven or knitted into fabrics commonly found in clothing.

Damage may be mechanical or chemical. Mechanical damage is seen as breaks, tears, or punctures; insect activity causes such damage. Chemical damage derives from exposure to the sun, chemicals in the soil, heat, and microbial activity (Morse et. al., 1984; Joseph, 1977). Such damage can be noted through a number of tests, including but not limited to: visual and microscopic examination, breaking and bursting strengths, moisture regain, solubility, burning, and elongation and elasticity.

In their study, Morse et al (1984) used visual and microscopic evaluation (optical microscopy and scanning electron microscopy), breaking and bursting strength, soft x-rays, and chemical tests. However, they found that scanning electron microscopy was too expensive and time-consuming for the minimal results, and x-rays and chemical tests were similarly useless.

CHAPTER III

METHODS AND MATERIALS

THE EXPERIMENT

Two human cadavers were placed at the Anthropology Research Facility on January 16, 1991. One was clothed, the other nude. Cotton, scoured wool, silk, nylon 6.6, polyester (dacron 54), acrylic (orlon 75), and acetate yarns were attached to the inner surface of the clothing, while another set of these yarns was laid on the surface near the clothed body (but not associated with it). Observations of environmental variables and the presence/absence of insect activity were noted, and the decomposition processes of the clothed and nude cadavers were monitored for variation.

Samples of the yarns from the clothed cadaver and from the control set were collected. Deterioration was measured at TRID facilities on the UT campus. These results were compared with a control set protected from the environment.

SUBJECTS

Two cadavers were delivered to the Anthropology Research Facility in Knoxville, TN on January 15, 1991. They were obtained through Dr. William Bass and the Tennessee State Medical Examiner's Office. On January 16, 1991, one of the cadavers was moved to a location within 5 feet of the other experimental subject, so that they would share similar sun/shade, precipitation and drainage exposure.

The control cadaver was a black male aged 81 years at death. He died on October 30, 1990 of cardiopulmonary arrest and was stored in the Forensic Sciences Center cooler until removal on January 15, 1991 to the Anthropology Research Facility.

The experimental cadaver was a white male aged 65 years at death. He died on November 15, 1990 of natural causes and was stored in the Forensic Sciences Center cooler until removal on January 15, 1991 to the Anthropology Research Facility. When received, mold was observed covering his face with spots of mold on his chest. He was wearing a silver-colored watch on his left wrist.

THE FACILITY AND SUBJECT PLACEMENT

The Anthropology Research Facility is an acre of fenced, open wooded land located behind the University of Tennessee Memorial Hospital, a few miles south of the University proper (see Figure 1). Experimental and control cadavers were placed in locations with mixed sun/shade exposure about five feet from one another on a slight incline (see Figure 2). The surface was comprised of soil and leaf clutter. The experimental cadaver (EXP) was clothed and placed on his back, arms and legs slightly spread, palms down. The control cadaver (CTL) remained unclothed. He was resting partially on his left side, back to the ground. His legs were drawn up and his hands rested on his chest. Attempts were made to straighten the cadaver to match the position of EXP, but given the amount

Figure 1.
Anthropological Research Facility

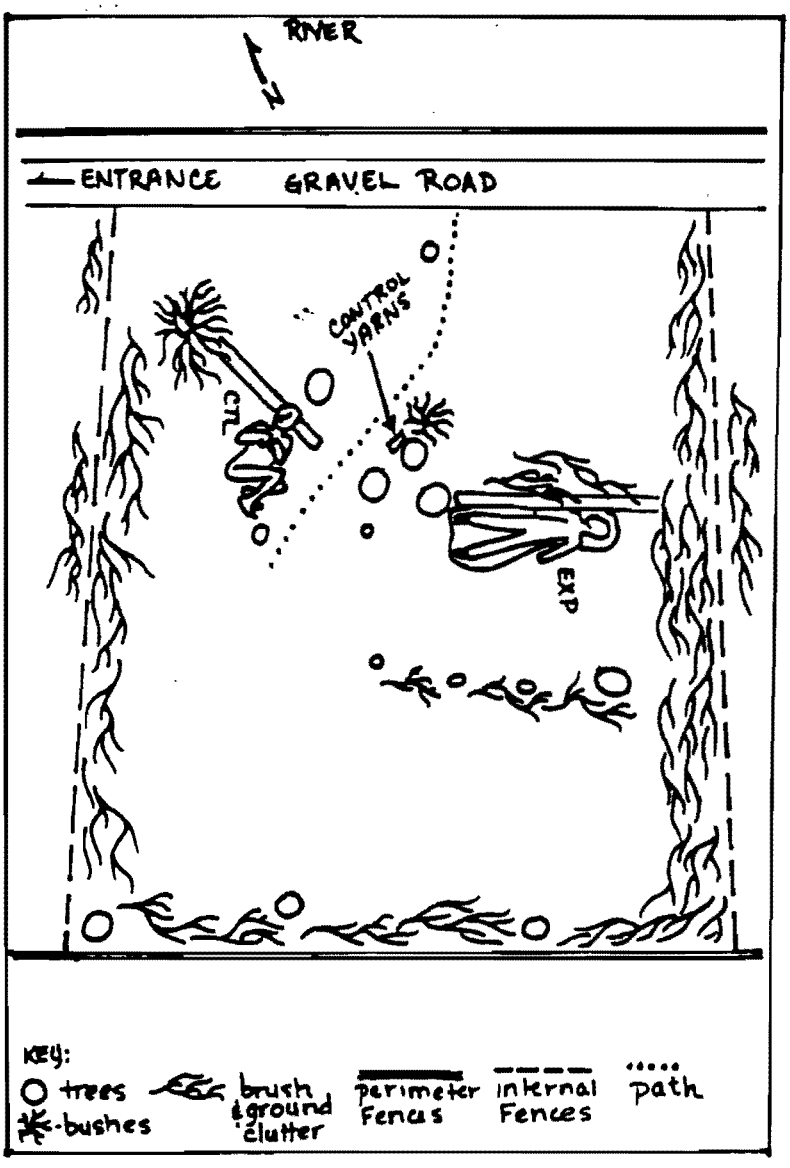

Figure 2.
Sketch of placement of experimental cadavers and yarns at the Anthropological Research Facility

of resistance encountered, it was decided to leave the limbs as they were and avoid any unnecessary trauma.

CLOTHING SPECIFICATIONS

A garment was made for EXP. The left side of the garment was unbleached cotton (Style # 400 U, Testfabrics Technical Catalog, Issue #64),[2] and the right side was spunbonded polypropylene.[3] A vertical opening from neck to crotch and a horizontal opening at waist level were fastened with velcro. These openings permitted easy observation of decomposition and easy access to yarns, while eliminating the unwieldiness of buttons and possible malfunction of zippers (Figure 3).

A combination of cotton and polypropylene was used in order to observe the differences between two extremes. Polypropylene is a man-made non-cellulosic fabric which absorbs essentially no water, while cotton is a natural cellulosic fabric which absorbs water easily. By using both fabrics, two extremes could be evaluated for their ability to facilitate/inhibit decomposition and for the deterioration involved.

EXP was wrapped in plastic sheeting when delivered. This plastic sheeting was left in place under EXP, between

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[2] All fabrics except for the polypropylene were ordered from TestFabrics, Inc./P.O.Box 420/200 Blackford Ave./ Middlesex, NJ 08846/(201) 269-6446.

[3] Non-woven fabric. Fabric weight = 50 grams/(meter)^2
Polymer ID: PP 3445
Pigment Concentration - 0.7% (w/w) color blue
Provided by TANDEC, UTK

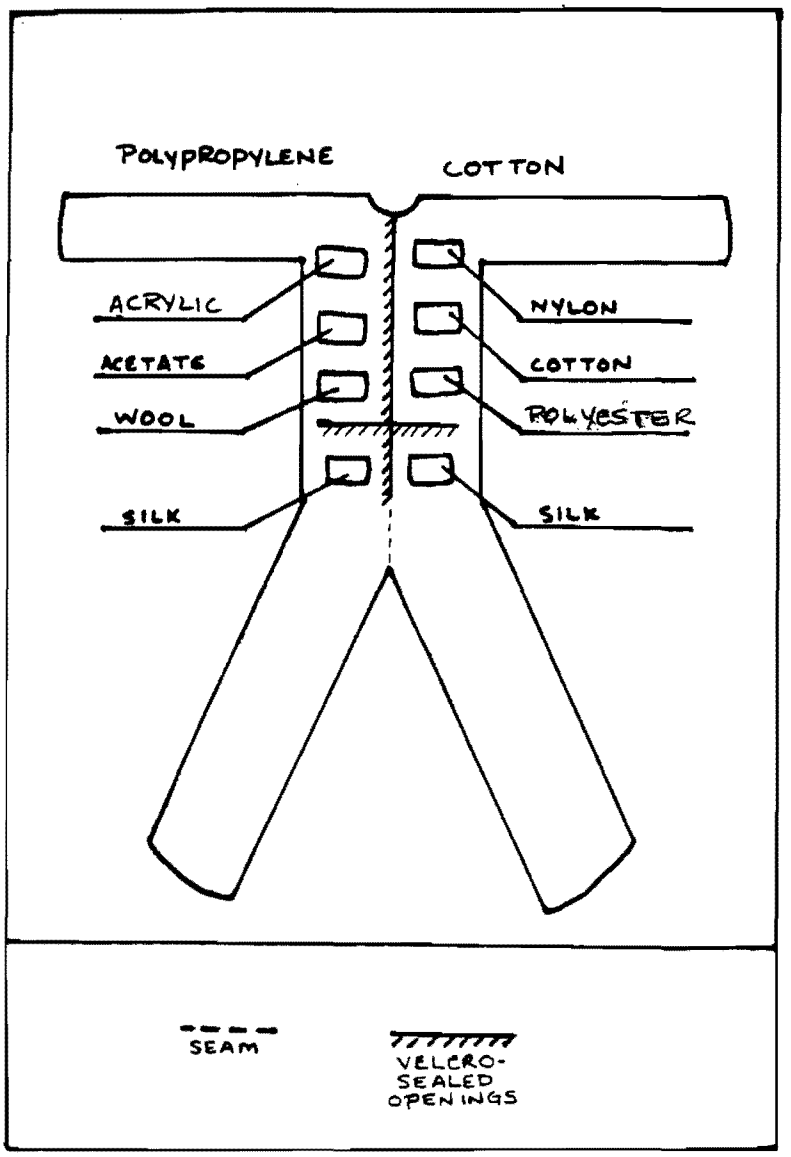


Figure 3.
Garment for experimental cadaver
and the placement of experimental yarns

the garment and the ground. No plastic sheeting was associated with CTL. It was decided to limit exposure of the garment to body fluids only, rather than to body fluids and soil. As a partial control, the arms of EXP were allowed to rest on the soil directly.

YARNS

In order to evaluate the effects of decomposition on the deterioration of materials common to clothing, various yarns were attached to the inside of the garment worn by EXP (EXP-yarn). Yarns were chosen because a number of samples were needed for testing purposes and space was limited. In addition, by using yarns, it was not necessary to remove pieces of fabric from the garment.

Yarns used were: scoured wool, acetate, acrylic (orlon 75), nylon 6.6, polyester (dacron 54), unbleached natural cotton, and silk. These yarns were positioned inside the garment areas covering the chest and abdomen, where they could receive maximum exposure to decompositional processes while also being accessible to collection. They were tied to a thread which was attached to the garment itself, rather than being laid over the cadaver, so that once decomposition was well under way, they could be removed from the garment rather than somewhere within the body cavity (Figure 3).

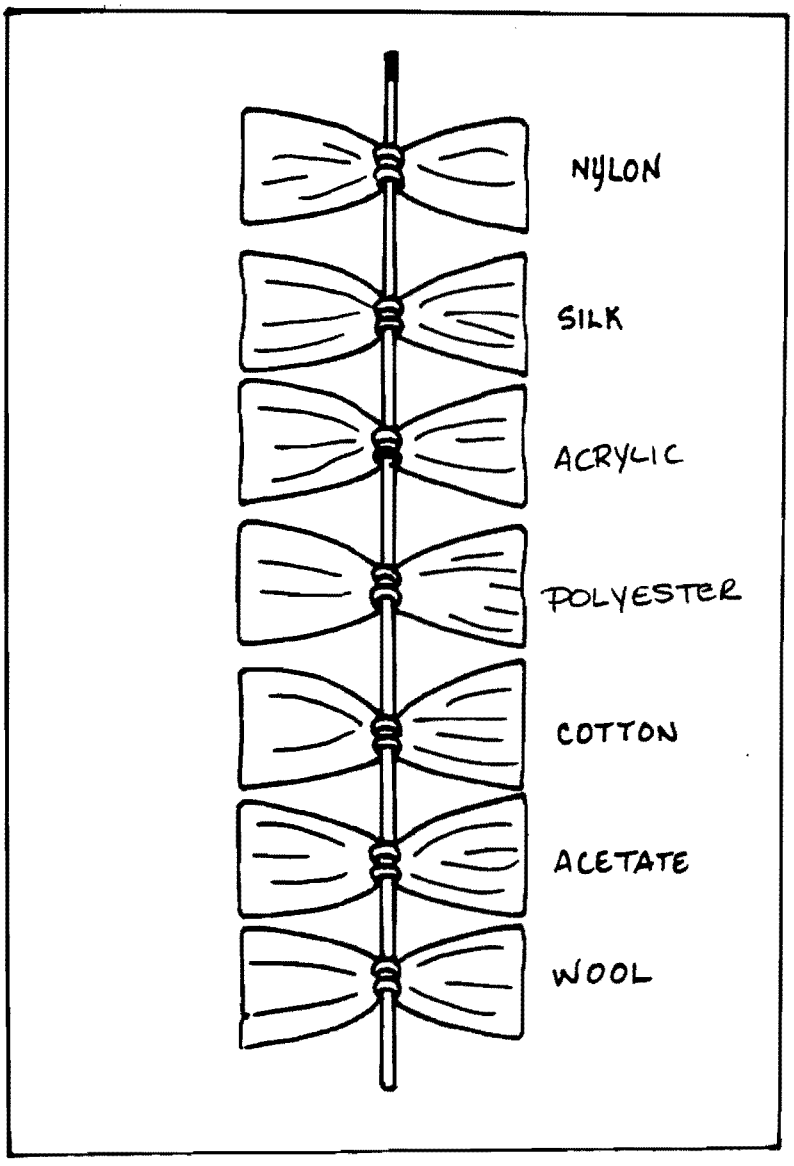
Control yarns (CLT-yarn) were attached to a polypropylene cord in batches. Plastic cording was chosen because there was little chance of it deteriorating and

contaminating the control samples in the time allotted for the experiment. The cord with the attached samples was tied loosely around the base of a tree, in contact with the ground surface, within 18 inches of EXP (Figure 4). In this way, the control and EXP samples were exposed to the same environmental conditions except for body fluids and amount of sunlight. Sunlight can have a significant effect on various fibers. However, in order to associate yarns directly with decomposition, the EXP-yarns were necessarily protected from direct sunlight. The control yarns were located in a shady area in an attempt to provide protection from direct sunlight and its affects. Although the CTL-yarns were located close to the decomposing body, their placement was such that they were protected from any seepage of body fluids.

A set of yarns was also kept away from all exposure, either to the environment or to decomposition (XYZ-yarn). These yarns provided an additional level of control against which the deterioration of both the CTL-yarn and the EXP-yarn can be compared.

OBSERVATIONS IN THE FIELD

Information on high and low temperatures and precipitation amounts on a daily basis for the duration of the experiment were obtained from the National Weather Service station at Tyson McGhee Airport a few miles south of the Facility. Humidity readings were not available from the Weather Service. In addition, monthly temperature



ARRANGEMENT

Figure 4.
Arrangement and placement of control yarns

PLACEMENT

Figure 4 (con't)

averages and precipitation amounts were collected from January 1986 through December 1990 for comparison to the readings for the time of the experiment (Table 1 and Figure 5).

Stages of decomposition were defined as follows:

FRESH: Processes of rigor, algor, and livor mortis
Some discoloration due to internal decomposition

BLOAT: Skin slippage
Seepage of body fluids from natural orifices, traumatic orifices
Hair loss (bodily and head)
Skin discoloration
Inflation of the abdominal and thoracic cavities due to build up of gases
Deflation after release of gases

DECAY: Cracks in the skin
Soft tissue deterioration
Exposure of bone
Continued seepage of body fluids, not limited to previous natural orifices, as these areas are destroyed during this stage
Presence of mold and fungal and bacterial colonies in the areas of seepage and on the body itself
Presence of hair mat

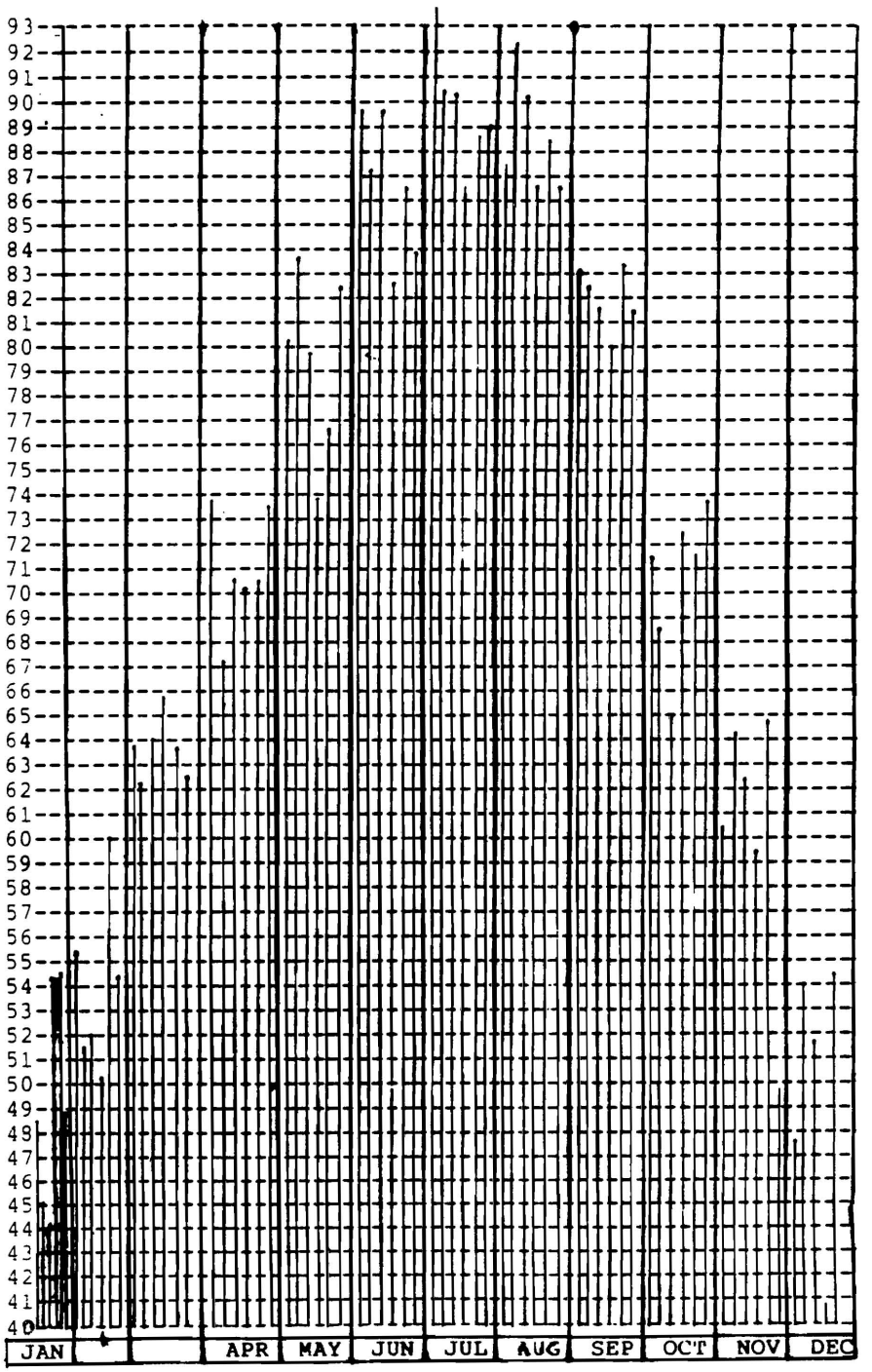
DRY: Little soft tissue remaining
Bones fully exposed
Bones greasy to dry
Bones disarticulated -- little cartilage or other connective tissue left
Deterioration of hair mat

Remains were watched for the presence/activity of small scavengers (mice, rats, chipmunks, birds, etc.; the fencing surrounding the Facility blocks access to larger scavengers such as raccoons, possums, domestic cats, dogs, etc.). Insect presence and activity was recorded, with estimates of number and descriptions of behavior.

Samples of EXP-yarns and CTL-yarns were collected for

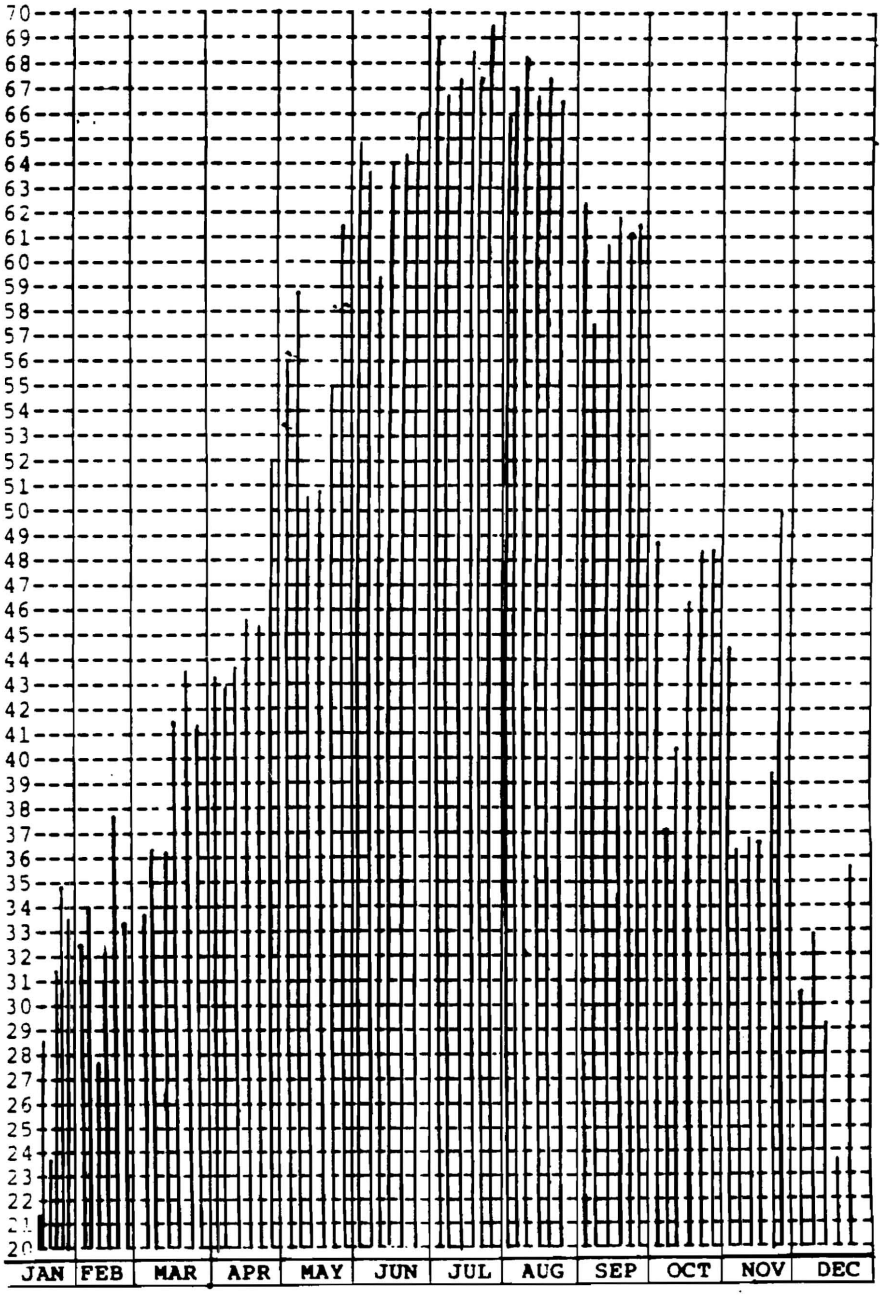
	JAN			FEB			MAR			APR			MAY			JUN			JUL			AUG			SEP			OCT			NOV		
DAY	HIGH	LOW	PREC	HIGH	LOW	PREC	HIGH	LOW	PREC	HIGH	LOW	PREC	HIGH	LOW	PREC	HIGH	LOW	PREC	HIGH	LOW	PREC	HIGH	LOW	PREC	HIGH	LOW	PREC	HIGH	LOW	PREC	HIGH	LOW	PREC
01	49	26	0.00	53	22	0.00	68	51	0.31	70	42	0.00	80	52	0.00	89	67	0.26	90	71	0.00	90	67	0.00	90	69	0.00	79	54	0.00	67	49	0.11
02	48	34	T	59	23	0.00	74	57	0.00	71	38	0.00	73	49	0.00	89	68	0.99	93	69	1.03	93	68	0.00	85	70	0.06	79	55	0.00	50	15	0.00
03	45	35	T	63	26	0.00	68	33	1.18	73	49	0.00	83	45	0.02	84	67	0.12	88	69	0.00	94	69	0.00	77	67	0.00	80	60	0.00	46	10	0.00
04	43	34	0.00	67	31	0.00	39	33	0.09	73	47	T	78	59	T	86	67	T	86	69	0.40	93	72	0.00	84	66	0.00	83	56	0.00	38	26	0.00
05	60	41	0.00	60	44	0.05	59	30	0.00	71	56	0.58	75	61	0.27	81	61	0.00	84	70	0.15	93	69	0.00	85	66	T	80	50	0.28	48	21	0.00
06	56	47	T	62	50	0.09	65	44	0.20	78	51	0.00	72	51	T	79	58	T	90	67	0.00	96	69	0.00	84	70	T	60	39	0.00	---	---	---
07	53	45	0.00	57	40	T	55	39	0.00	82	52	0.00	73	43	0.00	80	56	0.00	90	72	0.00	94	71	1.08	88	66	0.00	59	34	0.00	---	---	---
08	47	44	0.03	45	34	0.00	52	36	0.00	78	61	0.45	80	48	T	81	56	0.00	88	72	0.00	90	69	0.39	87	65	0.00	68	34	0.00	---	---	---
09	48	43	T	58	27	0.00	58	27	T	76	60	0.24	79	59	0.07	84	58	0.00	89	66	0.00	85	70	1.75	87	66	0.00	72	40	0.00	---	---	---
10	52	42	0.46	61	29	0.00	51	30	0.00	72	48	0.02	83	61	T	85	60	0.00	91	70	0.84	82	69	0.29	82	69	0.00	72	46	0.00	---	---	---
11	51	49	0.25	50	31	0.00	57	28	0.00	74	46	0.00	83	65	0.00	84	63	0.02	87	69	0.00	86	66	0.00	85	68	T	72	50	0.00	---	---	---
12	52	33	T	59	33	0.00	59	37	0.29	64	55	0.04	78	65	1.29	75	68	1.09	92	71	0.16	78	68	0.00	89	67	0.00	73	48	0.00	---	---	---
13	37	26	0.00	57	47	0.70	68	45	0.25	73	53	0.30	80	64	T	85	68	0.00	90	71	T	83	67	0.00	93	68	T	67	44	0.00	---	---	---
14	51	23	0.00	56	31	0.17	48	40	T	74	56	0.00	84	63	0.00	87	68	0.00	88	69	0.00	76	64	0.60	94	70	0.00	74	39	0.12	---	---	---
15	50	25	0.14	31	12	T	55	35	T	76	59	0.01	87	64	0.00	89	69	0.30	86	67	0.01	84	63	T	94	69	0.00	60	51	0.70	---	---	---
16	51	42	0.19	34	08	T	65	39	0.00	80	52	0.00	87	66	0.30	83	70	0.07	90	69	0.00	86	61	0.00	92	71	T	61	43	0.00	---	---	---
17	51	38	0.00	39	25	1.63	61	43	0.34	83	48	0.00	87	64	0.00	86	70	0.11	88	67	0.02	86	64	0.00	93	72	0.00	66	35	0.00	---	---	---
18	53	34	0.00	54	34	3.37	61	46	0.17	83	50	T	88	67	0.05	88	70	T	85	71	0.08	86	69	0.55	92	69	1.00	75	36	0.00	---	---	---
19	43	37	0.18	61	49	1.37	61	39	0.00	74	60	1.21	81	63	0.41	84	71	T	89	70	0.00	86	67	0.15	71	53	0.50	75	43	0.00	---	---	---
20	48	38	0.07	58	43	0.19	69	38	0.00	64	49	0.08	71	59	0.07	86	70	T	90	71	0.00	78	62	0.00	67	49	0.00	69	45	0.00	---	---	---
21	38	22	0.01	57	39	0.00	71	58	0.00	55	47	T	80	62	0.00	87	70	0.05	93	71	0.00	82	58	0.00	75	49	0.00	72	47	0.00	---	---	---
22	32	20	T	58	46	0.01	76	58	0.20	62	46	0.00	85	62	0.00	84	67	1.60	94	71	0.00	84	60	0.00	77	54	0.00	72	48	0.00	---	---	---
23	46	18	0.00	56	41	0.19	75	55	0.75	71	47	T	84	68	0.00	84	68	0.11	93	73	0.00	86	60	0.00	71	61	0.00	77	50	T	---	---	---
24	42	32	0.00	57	39	0.00	72	53	0.00	72	51	0.00	87	63	0.04	82	67	0.22	94	70	0.22	87	62	0.00	64	59	1.04	82	53	0.00	---	---	---
25	45	24	0.00	52	33	0.32	75	43	0.00	75	46	0.00	87	66	T	71	66	1.07	86	69	0.00	87	69	T	82	50	0.54	82	56	0.00	---	---	---
26	51	22	0.00	44	32	T	81	42	0.00	80	55	0.00	90	66	0.00	72	64	0.01	89	70	0.06	76	68	0.87	71	47	0.00	83	55	0.00	---	---	---
27	55	25	T	53	29	0.00	76	65	0.55	79	60	0.43	85	70	0.60	82	64	0.03	87	69	0.00	86	68	0.00	70	44	0.00	81	58	0.00	---	---	---
28	56	40	0.04	62	30	0.00	70	50	0.17	76	60	0.01	86	72	0.03	88	67	0.00	84	68	0.50	90	69	0.00	74	44	0.00	85	59	0.00	---	---	---
29	58	34	0.00	---	---	-----	56	40	1.86	73	61	0.48	89	71	0.00	90	69	0.00	85	70	0.00	89	69	0.32	79	49	0.00	78	60	0.00	---	---	---
30	56	39	0.54	---	---	-----	46	33	0.00	72	55	0.10	89	70	0.00	91	70	0.00	89	69	0.00	86	58	0.13	82	51	0.00	73	51	0.00	---	---	---
31	44	30	0.00	---	---	-----	58	31	0.00	---	---	-----	92	70	0.00	---	---	-----	89	68	0.00	89	67	0.00	---	---	-----	77	54	0.00	---	---	---
AVE	48.8	33.5	-----	54.4	33.1	-----	62.6	41.3	-----	73.5	52.0	-----	82.5	61.5	-----	83.9	65.9	-----	89.0	69.6	-----	86.5	66.5	-----	81.9	61.1	-----	73.8	48.2	-----	49.8	32.2	-----
TOT	---	---	2.53	---	---	6.99	---	---	6.36	---	---	3.97	---	---	3.10	---	---	6.01	---	---	1.45	---	---	6.13	---	---	3.14	---	---	1.10	---	---	0.11

Table 1.
Daily high/low temperatures in degrees Fahrenheit
Daily precipitation in inches
Average monthly high/low temperatures in degrees Fahrenheit
Total precipitation in inches
January 1991 through November 1991



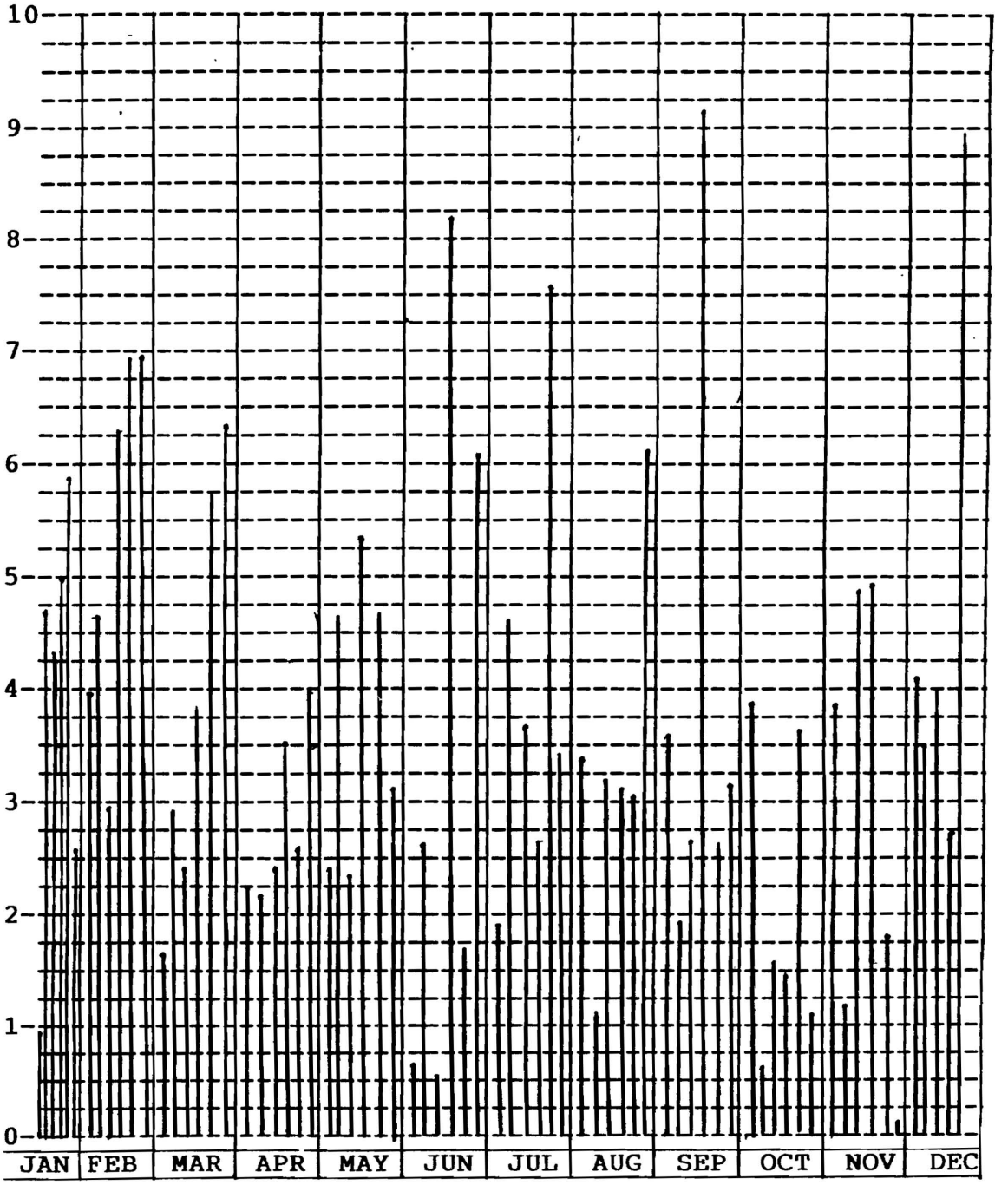
AVERAGE MONTHLY HIGH TEMPERATURES

Figure 5.
Average monthly high and low temperatures
in degrees Fahrenheit and
total monthly precipitation in inches
January 1986 through November 1991



AVERAGE MONTHLY LOW TEMPERATURES

Figure 5. (con't)



TOTAL MONTLY PRECIPITATION

Figure 5. (con't)

later study in the lab. At least 3 yarns were included in each sample taken.

Photographs were taken of the cadavers and the surroundings throughout the experiment. Kodak color film, 35 mm, 200 ASA speed. The camera was a Vision II Motor Advance by ANSCO with an focus-free f5.6 lens and a built-in flash. The majority of the photographs were taken using the flash, regardless of the amount of sunlight present; photo quality was much improved with the use of the flash.

Originally, the facility was to be visited and yarn samples collected every day for the first 3 months, twice a week for the next 3 months, and once a week for the remainder of the experiment. Because of placement during the colder winter months, little change was noted and visits and collections were reduced to save the limited yarns samples. The schedule was further disrupted by unanticipated practical and job-related consideration. The site was visited and samples collected on the following dates:

01/16/91	02/01/91	03/04/91	09/29/91
01/17/91	02/02/91	03/14/91	10/28/91
01/18/91	02/04/91	03/30/91	11/05/91
01/19/91	02/08/91	05/02/91	
01/20/91	02/10/91	05/04/91	
01/22/91	02/22/91		
01/25/91	02/25/91		
01/26/91	02/26/91		
01/28/91			
01/29/91			

LABORATORY PROCEDURES

Procedures included visual examination of yarns, microscopic examination of fibers, and breaking strength of yarns. Visual examination included observations of color changes, luster changes, fragility, and the presence of adherent particles. Microscopic examination of fibers involved cutting a 1/4 inch length from the end of the yarns, removing a number of fibers with tweezers and placing them on a microscope slide. The fibers were dry-mounted; no reagents, stains, or water were used for mounting. Cover slides were placed over the fibers and the edges taped down with transparent adhesive tape. The fibers were then examined under 2.5x, 10x, and 40x magnification using a stereomicroscope and a Zeiss polarizing microscope. Diameter of the fibers was measured in micrometers at 40x magnification. Although 63x and 100x magnification were available, visualization was not clear at these stages. Fibers were examined for cracks, ruptures, breaks, tears, changes in diameter, adherents, and other signs of deterioration. Figure 6 shows the normal structure of the seven types of fibers under 40x magnification.

Breaking strength was measured with an Instron Tensile Machine. A 200 pound load cell was used. Clamp pressure was set at 50 psi. Cross Head Speed (CHS) was set at 5 inches/minute; Chart Speed (CS) was set at 10 inches/minute. Full Scale Load was set at 10 pounds. Gage

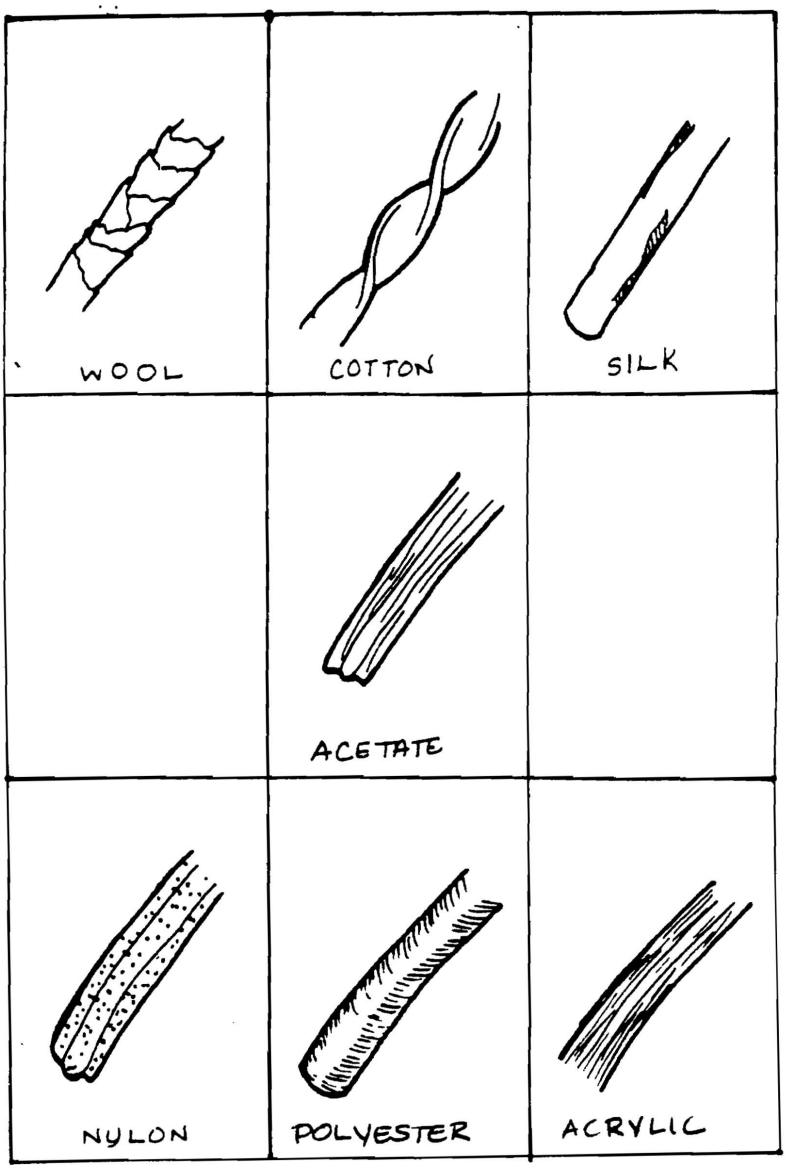


Figure 6.
Appearance of fibers from normal yarns
at 40x magnification

length was one inch. The amount of force required to break the yarns (breaking strength) could be measured in pounds simply by reading the charts produced.

T-Tests were used to compare the breaking strengths of EXP-yarns and CTL-yarns from each sample and with the XYZ-control yarns, in order to see how they reacted when exposed to different environmental and decompositional factors.

n = number of yarns tested per sample

y_i = the breaking strength of each yarn specimen

$$\bar{y} = \sum_{i=1} y_i/n$$

$$s^2 = 1/n-1\ [\Sigma y_i^2 - (\Sigma y_i)^2/n]$$

$$s = \sqrt{[(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2]/n_1 + n_2 - 2}$$

$$t = (\bar{y}_1 - \bar{y}_2)/s\sqrt{1/n_1 + 1/n_2}$$

$$df = n_1 + n_2 - 2$$

df - degrees of freedom
subscript '1' and '2' refer to sample group
subscript 'i' refers to individual specimen in a sample group

Values of T were compared with the values in Table 4: Percentage Points of the t-distribution, in An Introduction to Statistical Methods and Data Analysis by Lyman Ott

Figure 7.
Equations used in the Comparison of Yarn Samples

CHAPTER IV

RESULTS

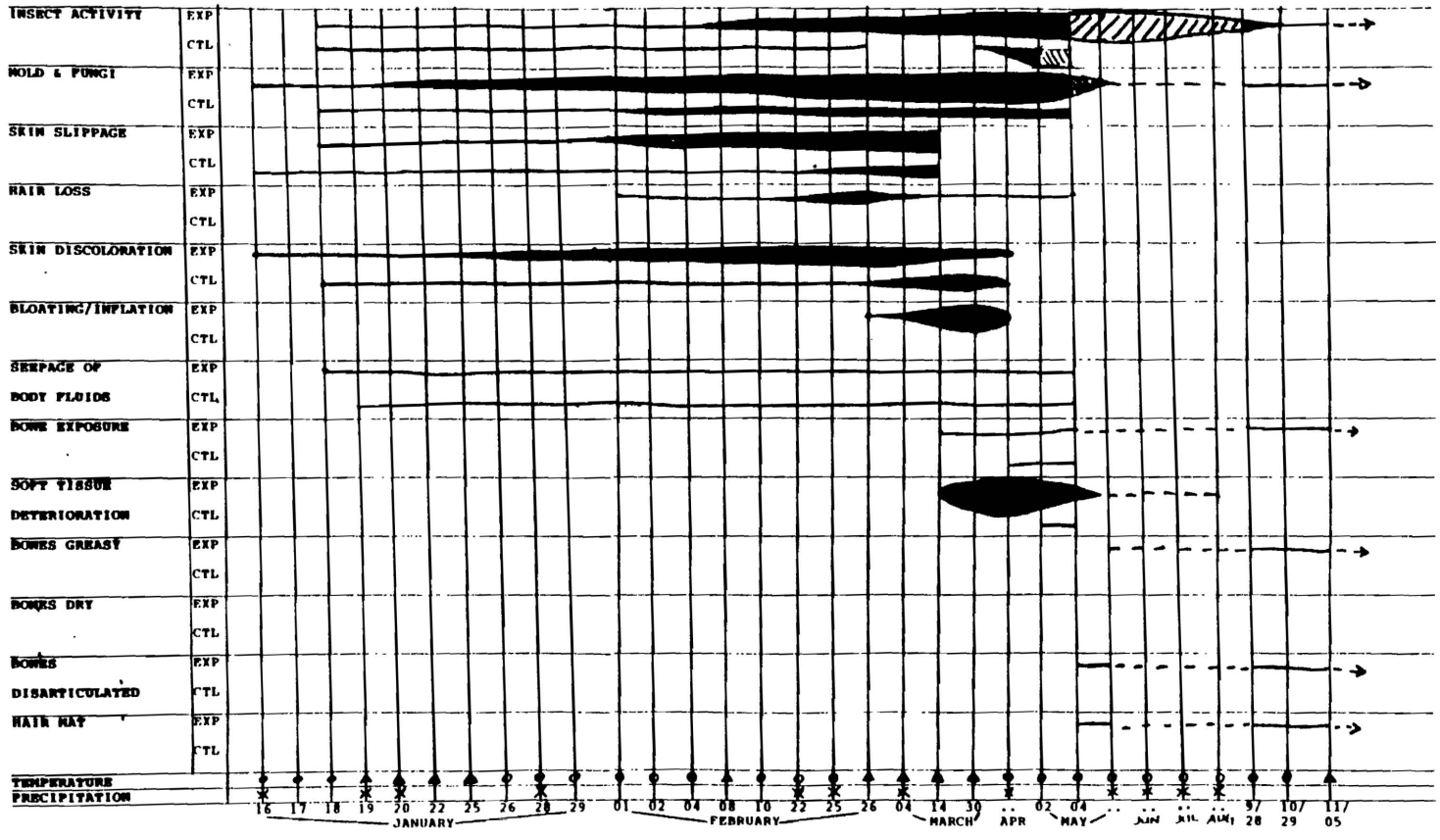
DECOMPOSITION

Evaluation of human decomposition is based on the criteria detailed in the previous chapter. Figure 8 provides a chart showing when major criteria in this study began, peaked, and ended.

EXP and CTL were in the late part of fresh/very early bloat when they were placed at the Facility on January 15, 1991. CTL exhibited initial skin slippage along his legs. EXP's face was covered by mold and showed some discoloration, but there were no other signs of active decomposition. At placement, there was no apparent insect activity associated with EXP or CTL, although some flies were observed in association with other remains at the Facility.

On January 18, 1991 seepage of body fluids from EXP was staining the cotton part of the garment. No inflation was noted. Slight skin slippage was noted on the feet and the torso. The mold and fungus was spreading slowly from the face in quarter sized spots to the upper torso.

CTL showed some facial discoloration. His fingertips shrivelled, and the skin on his chest where his hands rested was greenish and decaying. Fungus began to appear in the groin, navel and mouth; it was white with a cottage cheese-like consistency. Fly and ant activity was noted in small numbers around the faces of both CTL and EXP, as well



Key:

▲ = High Temperature Below 50 F

● = High Temperature Above 50 F

X = Rainfall Recorded for Day

Solid lines and areas indicate observed data
Broken lines and areas indicate speculated events

Figure 8.

Beginnings, Peaks, and Ends of Decomposition Stages and Related Activities

inside EXP's garment.

Through the end of January, mild skin slippage continued in both cadavers. Mold and fungal growth continued on EXP over the chest, down the abdomen, and onto the legs. By January 25, the white fungus on CTL had spread from the mouth over most of the face and from the groin to the mid-abdomen.

Insects continued to concentrate on CTL's face, but on EXP activity was noted both inside the garment at the chest and abdomen as well as around the face. There was regularly two to three times as much insect activity associated with EXP than with CTL.

On February 1, 1991 EXP showed discoloration of the head (dark red to black), neck, feet and hands, and loosening of the hair. By February 4, facial skin slippage was beginning on EXP's face. Greenish/white mold formed on EXP's hands and arms and on CTL's left back and hip, where the body was in contact with soil and leaf clutter covering the ground. Within another few days, this was producing a green slime as the skin deteriorated.

Estimates of insect numbers during the first week and a half of February regularly ran about 10 + flies associated with CTL and 30 + with EXP. Most fly activity around CTL was concentrated on the face although it was observed on all parts of the body. Flies and ants associated with EXP were increasingly prevalent within the garment around the torso as well as around the face.

The last week in February saw more accelerated skin slippage. The garment stuck to underlying skin and pulled bits of skin away when it was opened. Numbers and types of insects increased. A spider was noted on EXP. By February 25, small maggots were noted in the groin area of EXP. They moved beneath loose skin or back toward garment folds when the body was uncovered on opening the garment. Maggots were also observed on CTL, beneath the body, inside the curled up hands, and on the chest where the hands were in contact with the chest; they too moved beneath any loose skin when the body parts over them were moved. Maggot masses were not large, and no maggots seen were larger than a quarter of an inch, either on CTL or EXP.

On February 25, EXP showed some puffiness in the lower abdomen and in the upper chest near the neck, indicating the beginning of inflation.

By March 14, deterioration was proceeding steadily on CTL, with slippage continuing as before and discoloration occurring on the chest and abdomen.[4] Degeneration of the facial features was noted, although no insect activity was observed. The maggots which had been previously present were not found, and there appeared to be little destruction in those areas. No evidence of puffiness or inflation was noted.

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[4] In general, when bodies begin to undergo discoloration, white individuals become darker, and black individuals become lighter. Such patterns were consistent with the observations made on EXP and CTL.

Decomposition of EXP was increasing by March 14. Facial slippage and tissue destruction was marked -- gums and teeth were fully exposed, cheeks were missing, and the nose and surrounding tissue gave the impression of sliding off the right side of the skull. The entire head was black. Maggot, fly, and ant activity was growing under the garment.

On March 30, 1991, CTL showed a marbled, reddish discoloration over most of the body. The skin looked like lightly tanned leather. Maggots were noted again in the same areas as before, at about the same stage of development. Insects, mostly flies, were flying around the body. Mold was present in the folds of joints (inner arm at elbow, etc.).

EXP exhibited significant inflation. The oversize garment was stretched over the torso. Insect activity and variety had increased, with most located under the garment. Maggots, ants, flies, spiders, and a dead wasp were seen. Large maggot masses extended along the sides of the body from the armpit down below the hip, and from the bottom of the garment up the sides about six inches. Feeding activity was extensive, with production of large amounts of yellowish/white foam.[5]

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[5] No mention of such foam was found in the literature. However, Dr. Neal Haskell (Entomology, Purdue University) suggested at a Forensic Conference in June, 1991 that this was a result of maggot digestion and metabolism and the reaction of digestive enzymes on the surrounding soft tissues.

By May 2, decomposition had progressed to the dry stage. Most bones were exposed, although some tissues still adhered in places to the bones. There was excesive insect activity still associated with EXP, with large swarms of small black flies in the immediate vicinity. In the bottom of the garment, two to four inches deep, and surrounding the bones, was a thick, yellowish/white substance the consistency of soft lard. Maggot activity was noted among this. No such substances were noted in the vicinity of CTL.

At this time, CTL was removed inadvertently by Facility managers, and no further comparisons between clothed and unclothed remains were possible.

Over the next several months, connective tissues (cartilage and ligaments) deteriorated and remaining soft tissues were removed. The substance in the bottom of the garment slowly deteriorated. By the end of September, there was perhaps one inch left, and the consistency was like very wet clay. The skeletal connective tissues (ligaments) were completely gone. The bones were still greasy, but no soft tissue remained. The only exception was a large, roughly oval shaped piece of dried, leathery skin adhering to the left side of the skull. Head hair was still attached to this. A hair mat was resting under the right side of the skull.

The cotton part of the garment was stiff. It had deteriorated over the arm, so that only fragmentary strips

lay over the radius, ulna and humerus. There were also tears and gaps over the torso. However, much of the fabric was folded over itself. As the soft tissues decayed, the fabric of the garment was no longer supported and began to collapse over the bones. As the bones collapsed or fell into the now empty thoracic cavity, the fabric fell with it. This minimized exposure of the bones and other contents of the garment to the environment. Out of curiosity, the garment was left open at this time to see what would happen to the substance surrounding the bones on exposure to rain and sunlight.

On October 28, 1991 fallen leaves from the surrounding trees covered most of the remains. The white substance was still preserved and moist in the folds of the cotton and polypropylene, and there were a few live and dead maggots in those areas. The areas where the garment had been pulled back were covered with leaves. The substance beneath the leaves was black and tarry on the surface, with some whitish remnants a little deeper. Leaf decay associated with the deterioration of this substance may have combined to form this tarry layer. It had a glue-like consistency.

The small bones of the hands and feet were still in place, with no evidence of scattering. Throughout the duration of the experiment, there was no evidence of the activity of small scavengers such as mice or birds. Several birds, including scavengers such as crows, were

heard on visits to the Facility, but none were observed anywhere near EXP or CTL. No gnaw marks were noted on the long bones such as the left humerus, radius or ulna, which were accessible to rodents because of cloth deterioration.

On November 5, 1991, most insect activity involved insects such as millipedes, small roaches, and small slugs. On the undersides of the garment, particularly where it was in contact with the ground rather than the plastic sheeting, there were large amounts of very timy white insects, probably larvae of some sort. These were observed feeding on remains of larger maggots on the inside of the garment.

CLOTHING AND YARNS

The Garment

Aside from stains caused by seeping body fluids, both the cotton and the polypropylene held up to decomposition well. In early May, both sides were still intact. By late September, the cotton exposed to the air and sun was stiff. Interestingly, the cotton beneath the body, between the body and the plastic sheeting, appeared intact and relatively resistant to tearing. The cotton around the left arm, which was in contact with the ground rather than the plastic sheeting, deteriorated equally on all sides. Aside from some color fading, the polypropylene suffered no apparent deterioration. It did not tear and gaps were not noted. However, the cotton was dirty and extensively mildewed.

The Yarns -- Visual Examination

See Figure 9 for results of visual examination. The yarns were examined for color and luster changes and differences in stiffness. It was found that by March 30, most of the EXP-yarns felt somewhat greasy. Discoloration of EXP-yarns was attributed to absorption of body fluids and rain water and the adhesion of insect fecal matter and dead skin. Discoloration of the CTL-yarns was attributed to absorption of rain, exposure to mud and mulch, and bits of dead leaves and other plants.

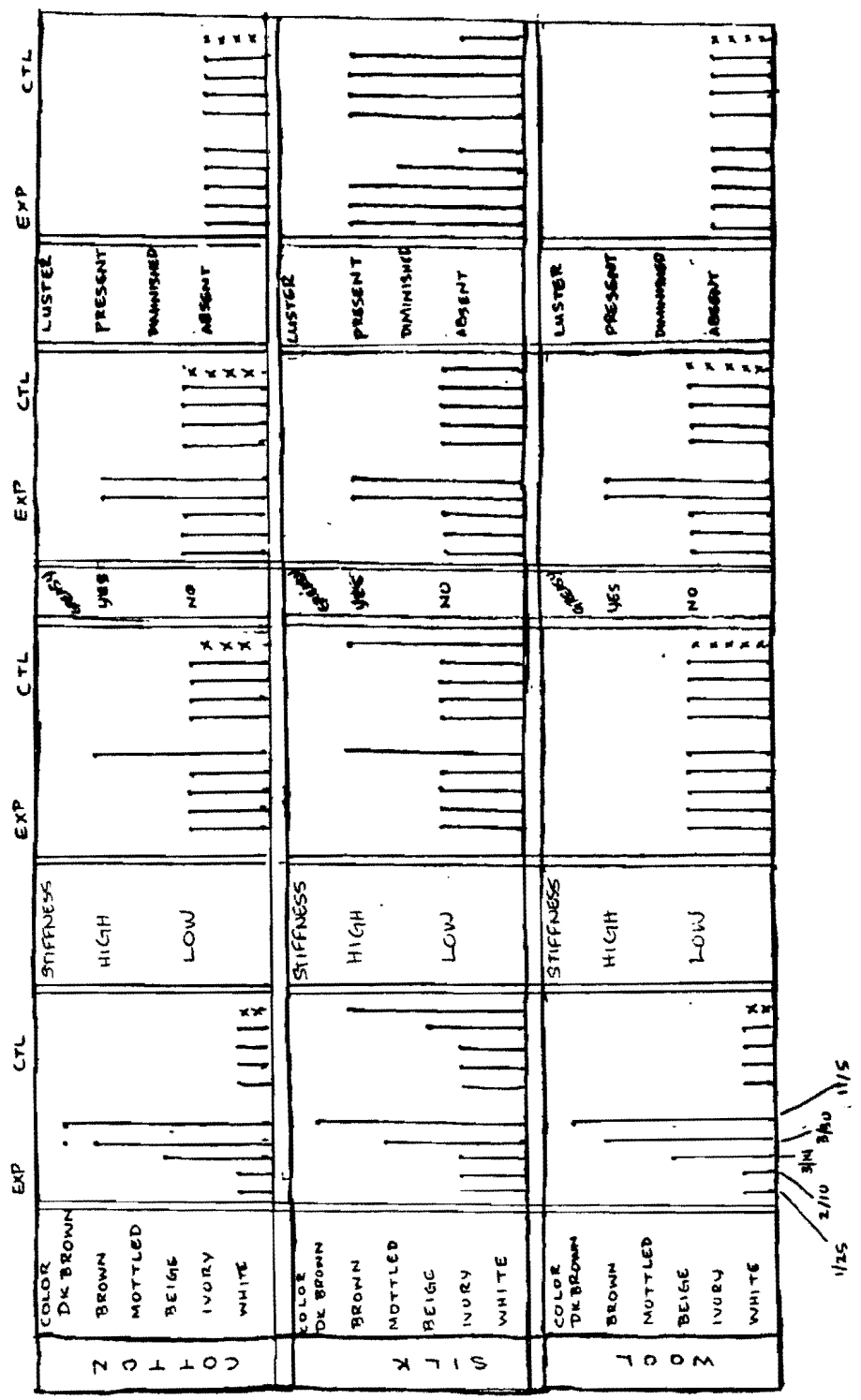
The Yarns -- Microscopic Evaluation of Fibers

Little damage was seen under microscopy. Diameters of the XYZ-fibers at 40x magnification were:

acetate	22.5 micrometers
wool	25.0 micrometers
silk	12.5 micrometers
polyester	15.0 micrometers
cotton	15.0 micrometers
acrylic	27.5 micrometers
nylon	25.0 micrometers

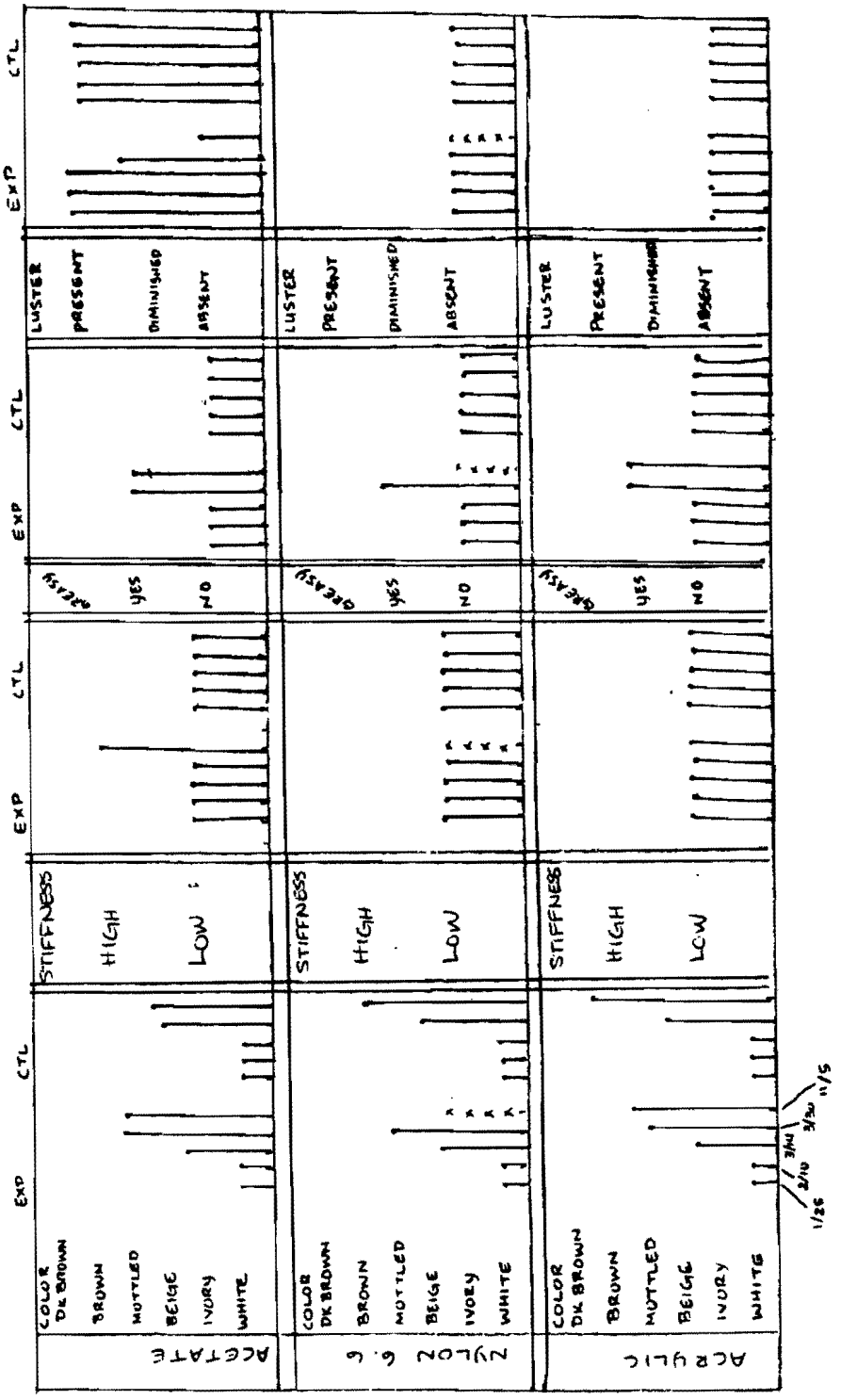
These remained consistent for all CTL-fibers and EXP-fibers. When making these measurements, several places on several fibers were examined.

The only unusual finding concerned nylon fibers from EXP-yarns collected on March 30, 1991. In these fibers, several swollen areas were noted, up to 42.5 micrometers. These areas were seen at 2.5x, 10x, and 40x magnification. However, it was difficult to tell if the fibers themselves were swollen in many places, or if there were fluid particles surrounding them. All yarn specimens



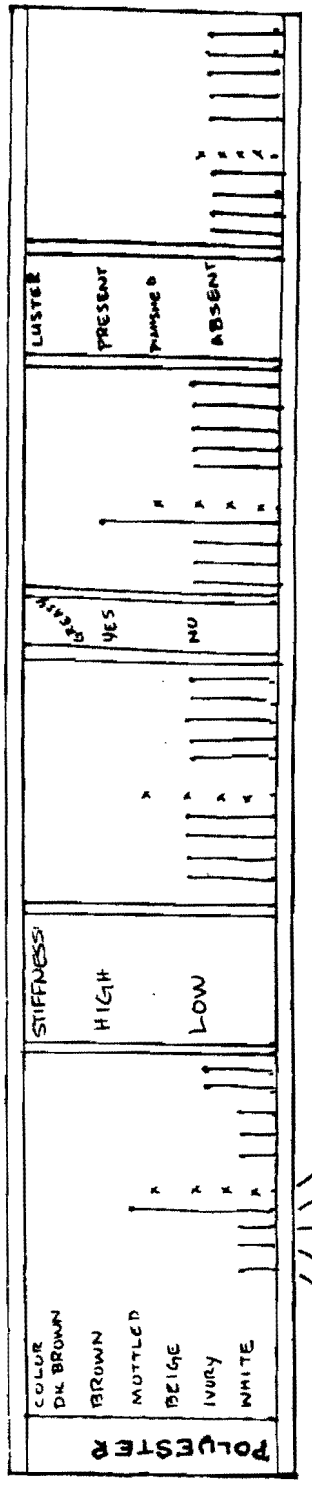
COTTON, SILK, WOOL

Figure 9.
Visual Examination of Yarns



ACETATE, NYLON 6.6, ACRYLIC

Figure 9. (con't)



POLYESTER

Figure 9. (con't)

were air dried. However, fibers were pulled from the ends of yarns, some from the inside portions of the yarns, and some from the outside. Fluid droplets may have adhered. No swelling was seen in any other fibers

Most fibers were associated with bits of adherents, with amounts increasing as time of exposure to the elements and to decomposition increased. Bits of dirt and leaf particles, and possibly insect feces were seen on the CTL-yarn fibers (on occasion small roaches and ants were noted moving over, under and through the yarns). Insects were not observed to be feeding on any of the CTL-yarns. Associated with the EXP-yarn fibers were flakes of dead skin, probable insect feces, and other bits of decomposition byproducts. In some cases flakes of skin were wrapped around the fiber; in other, very small bits of various adherents were attached to the surface of the fibers (looking much like very small pill-balls on a knitted sweater).

No apparent structural damage was noted. No cracks or bursted areas were seen.

The Yarns -- Breaking Strength

Raw data on breaking strengths of yarns in pounds and the results of the T-Tests and significant comparisons are in Table 2 and Figures 10 and 11. Figure 12 plots the relationships of the normalized mean breaking strengths of XYZ, EXP, and CTL samples. Table 3 gives mean and normalized breaking strengths for all samples.

Date	WOOL		COTTON		SILK		ACETATE		NYLON		POLYESTER		ACRYLIC	
	EXP	CTL	EXP	CTL	EXP	CTL	EXP	CTL	EXP	CTL	EXP	CTL	EXP	CTL
01/25/91	1.20	1.15	1.05	1.10	4.40	4.10	1.50	1.50	4.80	3.75	4.60	4.75	2.80	2.65
	1.05	1.40	0.90	1.10	4.10	4.50	1.00	1.10	4.40	3.55	4.30	4.90	2.65	3.10
	1.50	1.30	0.90	1.20	4.00	4.35	1.35	1.50	4.10	3.75	XXXX	4.20	2.80	2.60
02/10/91	1.00	1.20	1.00	1.15	4.05	4.1	1.20	1.10	3.75	3.00	4.80	5.00	2.85	2.95
	1.00	0.90	0.95	1.25	4.40	3.45	1.00	1.10	3.00	3.35	4.20	4.40	2.70	2.90
	1.25	1.20	1.00	0.95	4.30	XXXX	1.20	1.25	4.50	3.70	4.65	4.80	2.75	3.00
03/14/91	1.25	1.00	0.80	1.15	4.50	3.85	1.10	1.00	4.50	3.65	4.40	4.90	2.90	2.35
	1.15	1.20	1.20	1.15	4.20	3.30	1.10	1.30	3.55	3.60	4.30	3.85	2.70	2.40
	1.15	1.35	1.20	0.95	4.10	3.70	0.90	1.05	3.85	4.50	4.30	3.95	2.70	2.95
	XXXX	XXXX	XXXX	1.10	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
	XXXX	XXXX	XXXX	1.10	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
03/30/91	1.10	1.20	1.05	1.10	3.70	3.25	1.30	0.80	3.50	3.30	3.90	3.70	2.70	2.50
	1.40	1.35	0.90	1.10	3.30	3.30	0.80	1.05	3.85	3.25	3.75	4.00	2.80	2.80
	1.20	1.45	0.80	1.20	XXXX	3.45	1.35	0.80	3.50	3.70	4.00	3.90	2.60	2.90
	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	1.10	XXXX	XXXX	XXXX	4.50	XXXX	XXXX	XXXX
11/05/91	0.71	XXXX	0.50	XXXX	1.00	0.10	0.80	1.30	XXXX	3.55	XXXX	3.15	2.25	2.40
	0.66	XXXX	0.75	XXXX	1.10	0.05	0.70	0.95	XXXX	3.50	XXXX	3.80	2.85	1.95
	0.49	XXXX	0.80	XXXX	1.20	0.10	0.95	0.85	XXXX	2.95	XXXX	3.65	2.70	2.75
	XXXX	XXXX	XXXX	XXXX	0.70	XXXX	XXXX	XXXX	XXXX	3.20	XXXX	XXXX	XXXX	2.70

XYZ - YARNS

WOOL	COTTON	SILK	ACETATE	NYLON	POLYESTER	ACRYLIC
1.10	1.10	4.50	1.00	3.40	4.50	2.70
1.25	1.10	4.85	1.20	3.65	4.20	3.15
1.20	0.90	4.20	1.50	3.70	4.50	2.45
1.20	1.00	4.65	1.10	3.90	4.70	3.10
1.30	1.10	XXXX	1.30	4.05	5.20	2.65
1.35	1.10	XXXX	1.00	XXXX	XXXX	3.00
1.40	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX

Table 2.
Breaking Strengths of Individual Yarns in Pounds

	XYZ	EXP	CTL
01/25/91 Σy_2	8.8	3.75	3.85
Σy^2	11.13	4.79	4.97
n	7	3	3
$\bar{y}_2$	1.26	1.25	1.28
s^2	.012	.05	.015
s^2/n	.002	.017	.005

XYZ-EXP t .1
df 8
NS
XYZ-CTL t -.25
df 8
NS
EXP-CTL t -.2
df 4
NS

	XYZ	EXP	CTL
02/10/91 Σy_2	8.8	3.25	3.3
Σy^2	11.13	3.44	3.69
n	7	3	3
$\bar{y}_2$	1.26	1.08	1.1
s^2	.012	.04	.03
s^2/n	.002	.013	.01

XYZ-EXP t 1.86
df 8
a .05
XYZ-CTL t 1.78
df 8
NS
EXP-CTL t -.13
df 4
NS

	XYZ	EXP	CTL
03/14/91 Σy_2	8.8	3.55	3.55
Σy^2	11.13	4.21	4.26
n	7	3	3
$\bar{y}_2$	1.26	1.18	1.18
s^2	.012	.005	.03
s^2/n	.002	.002	.01

XYZ-EXP t 1.16
df 8
NS
XYZ-CTL t .89
df 8
NS
EXP-CTL t 0
df 4
NS

	XYZ	EXP	CTL
03/30/91 Σy_2	8.8	3.7	4
Σy^2	11.13	4.61	5.37
n	7	3	3
$\bar{y}_2$	1.26	1.23	1.33
s^2	.012	.025	.02
s^2/n	.002	.008	.007

XYZ-EXP t .38
df 8
NS
XYZ-CTL t -.88
df 8
NS
EXP-CTL t -.83
df 4
NS

	XYZ	EXP	CTL
11/05/91 Σy_2	8.8	1.86	xxx
Σy^2	11.13	1.18	xxx
n	7	3	xxx
$\bar{y}_2$	1.26	.62	xxx
s^2	.012	.015	xxx
s^2/n	.002	.005	xxx

XYZ-EXP t 8.00
df 8
a .001

WOOL

Figure 10.
Results of T-Tests to Determine Statistical Significance of Breaking Strengths of Yarn Samples

	XYZ	EXP	CTL
01/25/91 Σy_2	6.3	2.85	3.4
Σy^2	6.65	2.72	3.86
n	6	3	3
$\bar{y}_2$	1.05	.95	1.13
s^2	.007	.005	.005
s^2/n	.001	.002	.002

XYZ-EXP t 1.67
df 7
NS
XYZ-CTL t -1.33
df 7
NS
EXP-CTL t -3
df 4
a .025

	XYZ	EXP	CTL
02/10/91 Σy_2	6.3	2.95	3.35
Σy^2	6.65	2.90	3.79
n	6	3	3
$\bar{y}_2$	1.05	.98	1.12
s^2	.007	.001	.025
s^2/n	.001	.0003	.008

XYZ-EXP t 1.40
df 7
NS
XYZ-CTL t -.87
df 7
NS
EXP-CTL t -1.56
df 4
NS

	XYZ	EXP	CTL
03/14/91 Σy_2	6.3	3.2	5.45
Σy^2	6.65	3.52	5.97
n	6	3	5
$\bar{y}_2$	1.05	1.07	1.09
s^2	.007	.06	.008
s^2	.001	.02	.002

XYZ-EXP t -.20
df 7
NS
XYZ-CTL t -.67
df 9
NS
EXP-CTL t .17
df 6
NS

	XYZ	EXP	CTL
03/30/91 Σy_2	6.3	2.75	3.4
Σy^2	6.65	2.55	3.86
n	6	3	3
$\bar{y}_2$	1.05	.91	1.33
s^2	.007	.015	.005
s^2/n	.001	.005	.002

XYZ-EXP t 2.00
df 7
a .05
XYZ-CTL t -4.67
df 7
a .005
EXP-CTL t -5.25
df 4
a .005

	XYZ	EXP	CTL
11/05/91 Σy_2	6.3	2.05	xxx
Σy^2	6.65	1.45	xxx
n	6	3	xxx
$\bar{y}_2$	1.05	.68	xxx
s^2	.007	.025	xxx
s^2/n	.001	.008	xxx

XYZ-EXP t 4.63
df 7
a .005

COTTON

Figure 10. (con't)

	XYZ	EXP	CTL
01/25/91 Σy_2	18.2	12.5	12.95
Σy^2	83.04	52.17	55.98
n	4	3	3
$\bar{y}_2$	4.55	4.17	4.32
s^2	.08	.05	.04
s^2/n	.02	.02	.013

XYZ-EXP t 1.9
df 5
NS
XYZ-CTL t 1.21
df 5
NS
EXP-CTL t -.88
df 4
NS

	XYZ	EXP	CTL
02/10/91 Σy_2	18.2	12.75	7.55
Σy^2	83.04	54.25	28.71
n	4	3	2
$\bar{y}_2$	4.55	4.25	3.78
s^2	.08	.03	.21
s^2/n	.02	.01	.11

XYZ-EXP t 1.57
df 5
NS
XYZ-CTL t 2.75
df 4
a .05
EXP-CTL t 1.74
df 3
NS

	XYZ	EXP	CTL
03/14/91 Σy_2	18.2	12.8	10.85
Σy^2	83.04	54.7	39.40
n	4	3	3
$\bar{y}_2$	4.55	4.27	3.62
s^2	.08	.05	.08
s^2/n	.02	.02	.03

XYZ-EXP t 1.4
df 5
NS
XYZ-CTL t 4.43
df 5
a .005
EXP-CTL t 3.25
df 4
a .025

	XYZ	EXP	CTL
03/30/91 Σy_2	18.2	7	10
Σy^2	83.04	24.58	33.36
n	4	2	3
$\bar{y}_2$	4.55	3.5	3.33
s^2	.08	.08	.015
s^2/n	.02	.04	.005

XYZ-EXP t 4.38
df 4
a .01
XYZ-CTL t 7.17
df 5
a .001
EXP-CTL t .98
df 3
NS

	XYZ	EXP	CTL
11/05/91 Σy_2	18.2	4	.25
Σy^2	83.04	4.14	.023
n	4	4	3
$\bar{y}_2$	4.55	1	.08
s^2	.08	.05	.001
s^2/n	.02	.013	.0003

XYZ-EXP t 18.68
df 6
a .001
XYZ-CTL t 26.29
df 5
a .001
EXP-CTL t 7.08
df 5
a .001

SILK

Figure 10. (con't)

	XYZ	EXP	CTL
01/25/91 Σy	7.1	3.85	4.1
Σy^2	8.59	5.07	5.71
n	6	3	3
$\bar{y}$	1.18	1.28	1.37
s^2	.038	.065	.06
s^2/n	.006	.022	.02

XYZ-EXP t -.67
df 7
NS
XYZ-CTL t -1.27
df 7
NS
EXP-CTL t -.45
df 4
NS

	XYZ	EXP	CTL
02/10/91 Σy	7.1	3.4	3.45
Σy^2	8.59	3.88	3.98
n	6	3	3
$\bar{y}$	1.18	1.13	1.15
s^2	.038	.015	.005
s^2/n	.006	.005	.002

XYZ-EXP t .38
df 7
NS
XYZ-CTL t .25
df 7
NS
EXP-CTL t' -.25
df 4
NS

	XYZ	EXP	CTL
03/14/91 Σy	7.1	3.1	3.35
Σy^2	8.59	3.23	3.79
n	6	3	3
$\bar{y}$	1.18	1.03	1.12
s^2	.038	.015	.025
s^2/n	.006	.005	.008

XYZ-EXP t 1.15
df 7
NS
XYZ-CTL t .42
df 7
NS
EXP-CTL t -.82
df 4
NS

	XYZ	EXP	CTL
03/30/91 Σy	7.1	4.55	2.65
Σy^2	8.59	5.36	2.38
n	6	4	3
$\bar{y}$	1.18	1.14	.88
s^2	.038	.06	.02
s^2/n	.006	.015	.007

XYZ-EXP t .29
df 8
NS
XYZ-CTL t 2.31
df 7
a .05
EXP-CTL t 1.63
df 5
NS

	XYZ	EXP	CTL
11/05/91 Σy	7.1	2.45	3.1
Σy^2	8.59	2.03	3.32
n	6	3	3
$\bar{y}$	1.18	.82	1.08
s^2	.038	.015	.06
s^2/n	.006	.005	.02

ACETATE

XYZ-EXP t 2.76
df 7
a .025
XYZ-CTL t .67
df 7
NS
EXP-CTL t -1.63
df 4
NS

Figure 10. (con't)

	XYZ	EXP	CTL
01/25/91 Σy_2	18.7	13.3	11.05
Σy^2	70.9	59.21	40.73
n	5	3	3
$\bar{y}_2$	3.74	4.43	3.68
s^2	.06	.13	.015
s^2/n	.012	.04	.005

XYZ-EXP t -3.29
df 6
a .01
XYZ-CTL t .40
df 6
NS
EXP-CTL t 3.41
df 4
a .025

	XYZ	EXP	CTL
02/10/91 Σy_2	18.7	11.25	10.05
Σy^2	70.9	43.31	33.91
n	5	3	3
$\bar{y}_2$	3.74	3.75	3.35
s^2	.06	.56	.12
s^2/n	.012	.19	.04

XYZ-EXP t -.03
df 6
NS
XYZ-CTL t 2.0
df 6
a .05
EXP-CTL t .85
df 4
NS

	XYZ	EXP	CTL
03/14/91 Σy_2	18.7	11.9	11.8
Σy^2	70.9	47.68	46.53
n	5	3	3
$\bar{y}_2$	3.74	3.97	3.92
s^2	.06	.24	.06
s^2/n	.012	.08	.02

XYZ-EXP t -.89
df 6
NS
XYZ-CTL t -1.0
df 6
NS
EXP-CTL t .42
df 4
NS

	XYZ	EXP	CTL
03/30/91 Σy_2	18.7	10.85	10.25
Σy^2	70.9	39.32	35.14
n	5	3	3
$\bar{y}_2$	3.74	3.62	3.42
s^2	.06	.04	.06
s^2/n	.012	.013	.02

XYZ-EXP t .71
df 5
NS
XYZ-CTL t 1.78
df 6
EXP-CTL t 1.11
df 4
NS

	XYZ	EXP	CTL
11/05/91 Σy_2	18.7	xxx	13.2
Σy^2	70.9	xxx	43.8
n	5	xxx	4
$\bar{y}_2$	3.74	xxx	3.3
s^2	.06	xxx	.08
s^2/n	.012	xxx	.02

XYZ-CTL t 2.59
df 7
a .025

NYLON

Figure 10. (con't)

	XYZ	EXP	CTL
01/25/91 Σy	23.1	8.9	13.85
Σy^2	107.27	39.65	64.21
n	5	2	3
$\bar{y}$	4.62	4.45	4.62
s^2	0.14	0.04	0.14
s^2/n	0.028	0.02	0.05

XYZ-EXP t .58
df 5
NS

XYZ-CTL t 0
df 6
NS

EXP-CTL t -0.58
df 3
NS

	XYZ	EXP	CTL
02/10/91 Σy	23.1	13.65	14.2
Σy^2	107.27	62.30	67.4
n	5	3	3
$\bar{y}$	4.62	4.55	4.73
s^2	.14	.095	.095
s^2/n	.028	.032	.032

XYZ-EXP t .27
df 6
NS

XYZ-CTL t' -.42
df 6
NS

EXP-CTL t' -.72
df 4
NS

	XYZ	EXP	CTL
03/14/91 Σy	23.1	13	12.7
Σy^2	107.27	56.54	54.44
n	5	3	3
$\bar{y}$	4.62	4.33	4.23
s^2	.14	.005	.34
s^2/n	.028	.002	.113

XYZ-EXP t 1.26
df 6
NS

XYZ-CTL t 1.18
df 6
NS

EXP-CTL t .30
df 4
NS

	XYZ	EXP	CTL
03/30/91 Σy	23.1	16.15	11.6
Σy^2	107.27	65.52	44.9
n	5	4	3
$\bar{y}$	4.62	4.04	3.87
s^2	.14	.1	.017
s^2/n	.028	.02	.006

XYZ-EXP t 2.42
df 7
a .025

XYZ-CTL t 3.26
df 6
a .01

EXP-CTL t 0.85
df 5
NS

	XYZ	EXP	CTL
11/05/91 Σy	23.1	xxx	10.6
Σy^2	107.27	xxx	37.69
n	5	xxx	3
$\bar{y}$	4.62	xxx	3.53
s^2	.14	xxx	.12
s^2/n	.028	xxx	.04

XYZ-CTL t 4.04
df 6
a .005

POLYESTER

Figure 10. (con't)

	XYZ	EXP	CTL
01/25/91 Σy_2	17.05	8.25	8.35
Σy^2	48.85	22.70	23.39
n	6	3	3
$\bar{y}_2$	2.84	2.75	2.78
s^2	.08	.01	.08
s^2/n	.013	.003	.025

XYZ-EXP t .53
df 7
NS
XYZ-CTL t .29
df 7
NS
EXP-CTL t -.17
df 4
NS

	XYZ	EXP	CTL
02/10/91 Σy_2	17.05	8.3	8.85
Σy^2	48.85	22.98	26.11
n	6	3	3
$\bar{y}_2$	2.84	2.77	2.95
s^2	.08	.01	.002
s^2/n	.013	.003	.0007

XYZ-EXP t .39
df 7
NS
XYZ-CTL t -.64
df 7
NS
EXP-CTL t -2.57
df 4
a .05

	XYZ	EXP	CTL
03/14/91 Σy_2	17.05	8.3	7.7
Σy^2	48.85	22.99	19.99
n	6	3	3
$\bar{y}_2$	2.84	2.77	2.57
s^2	.08	.015	.115
s^2/n	.013	.005	.038

XYZ-EXP t .39
df 7
NS
XYZ-CTL t 1.29
df 7
NS
EXP-CTL t .95
df 4
NS

	XYZ	EXP	CTL
03/30/91 Σy_2	17.05	8.1	8.2
Σy^2	48.85	21.89	22.5
n	6	3	3
$\bar{y}_2$	2.84	2.7	2.73
s^2	.08	.01	.045
s^2/n	.013	.003	.015

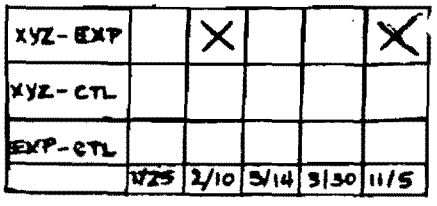
XYZ-EXP t .78
df 7
NS
XYZ-CTL t .61
df 7
NS
EXP-CTL t -.22
df 4
NS

	XYZ	EXP	CTL
11/05/91 Σy_2	17.05	7.8	9.8
Σy^2	48.85	20.48	24.42
n	6	3	4
$\bar{y}_2$	2.84	2.6	2.45
s^2	.08	.1	.14
s^2/n	.013	.033	.034

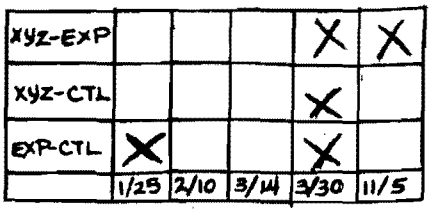
XYZ-EXP t 1.14
df 7
NS
XYZ-CTL t 1.86
df 8
a .05
EXP-CTL t .56
df 5
NS

ACRYLIC

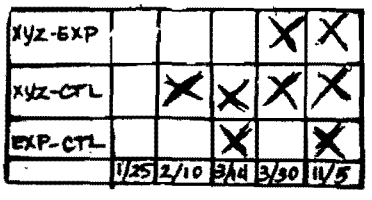
Figure 10. (con't)



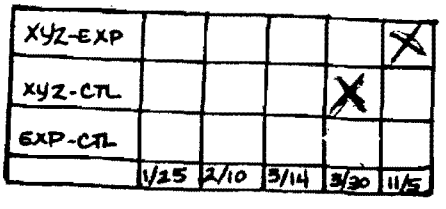
WOOL



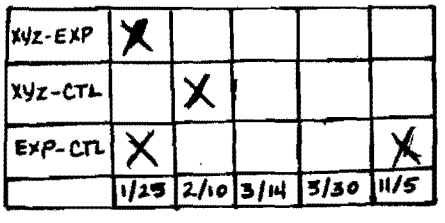
COTTON



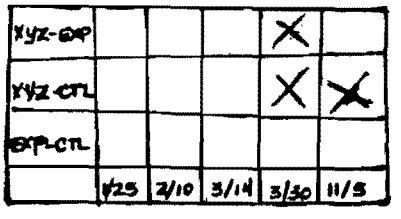
SILK



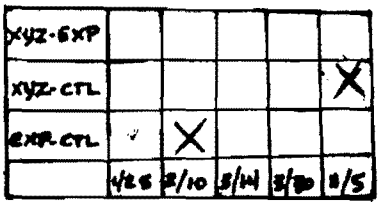
ACETATE



NYLON

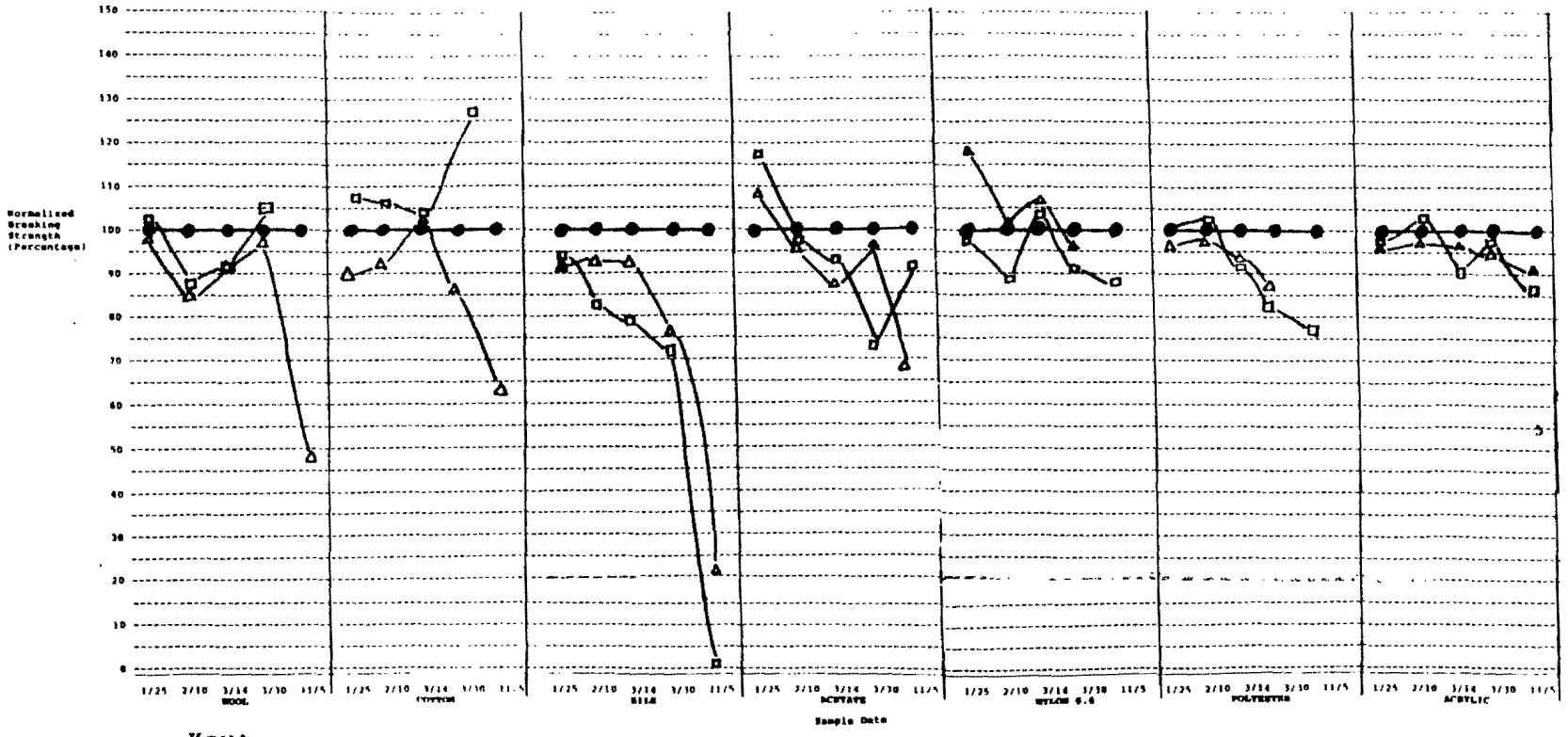


POLYESTER



ACRYLIC

Figure 11.
X indicates a Significant Comparison (at a = .05) Between Two Samples



Key:

● = XYZ-Yarns

△ = EXP-Yarns

□ = CTL-Yarns

Figure 12. Normalized Breaking Strengths of XYZ-, EXP-, and CTL-Yarns

DATE	WOOL						COTTON						SILK						ACETATE						NYLON						POLYESTER						ACRYLIC					
	EXP		CTL		XYZ		EXP		CTL		XYZ		EXP		CTL		XYZ		EXP		CTL		XYZ		EXP		CTL		XYZ		EXP		CTL		XYZ		EXP		CTL		XYZ	
	MBS	NBS	MBS	NBS	MBS	NBS	MBS	NBS	MBS	NBS	MBS	NBS	MBS	NBS	MBS	NBS	MBS	NBS	MBS	NBS	MBS	NBS	MBS	NBS	MBS	NBS	MBS	NBS	MBS	NBS	MBS	NBS	MBS	NBS	MBS	NBS	MBS	NBS	MBS	NBS	MBS	NBS
	---	---	---	---	1.26	100%	---	---	---	---	1.05	100%	---	---	---	---	4.55	100%	---	---	---	---	1.19	100%	---	---	---	---	3.74	100%	---	---	---	---	4.62	100%	---	---	---	---	2.84	100%
7/25	1.25	99%	1.28	101%	---	---	0.95	90%	1.13	107%	---	---	4.17	91%	4.32	95%	---	---	1.28	108%	1.17	116%	---	---	4.01	110%	1.68	98%	---	---	4.05	96%	4.62	100%	---	---	2.75	96%	2.78	97%	---	---
7/28	1.08	85%	1.18	93%	---	---	0.98	93%	1.12	106%	---	---	4.25	93%	3.78	83%	---	---	1.11	94%	1.15	97%	---	---	3.75	103%	1.35	89%	---	---	4.55	98%	4.73	102%	---	---	2.77	97%	2.95	103%	---	---
7/14	1.18	93%	1.18	93%	---	---	1.07	101%	1.09	103%	---	---	4.27	93%	1.62	79%	---	---	1.03	87%	1.12	94%	---	---	3.97	106%	1.57	104%	---	---	4.18	93%	4.23	91%	---	---	2.77	97%	2.53	90%	---	---
7/10	1.23	97%	1.33	105%	---	---	0.91	86%	1.13	108%	---	---	1.58	78%	1.33	73%	---	---	1.14	96%	0.88	74%	---	---	3.62	96%	1.42	94%	---	---	4.04	87%	1.82	83%	---	---	2.70	95%	2.73	96%	---	---
7/5	0.62	49%	---	---	---	---	0.68	64%	---	---	---	---	1.00	21%	0.08	1%	---	---	0.87	69%	1.08	91%	---	---	---	---	2.78	48%	---	---	---	---	3.53	76%	---	---	2.60	91%	2.45	86%	---	---

MBS = Mean Breaking Strength

NBS = Normalized Breaking Strength

NBS = ($S_{measured}$ / $S_{initial}$) x 100

where $S_{measured}$ = the mean breaking strength of EXP or CTL samples

and $S_{initial}$ = the mean breaking strength of XYZ samples

Table 3.
Average Mean Breaking Strengths in Pounds
and Normalized Breaking Strengths in Percentage

Polyester

Polyester EXP-yarns collected March 30, 1991 were significantly weaker than XYZ-yarns. No EXP-polyester was collected after March 30, 1991.

Polyester CTL-yarns showed signficantly lower breaking strengths than XYZ-yarns on March 30, 1991 and deteriorated even further by November 5, 1991.

There were no significant differences between the breaking strengths of EXP-polyester and CTL-polyester.

Nylon

On January 25, 1991, EXP-nylon was significantly stronger than XYZ-nylon, but showed no other significantly different breaking strengths from XYZ-nylon after that. No samples of EXP-nylon were recovered after March 30, 1991.

CTL-nylon was significantly weaker than XYZ-nylon in the February 10, 1991 samples only. CTL-nylon was significantly weaker than EXP-nylon in the January 25, 1991 and November 5, 1991 samples.

Acetate

EXP-acetate was significantly weaker than XYZ-acetate on November 5, 1991, but not before then. In the March 30, 1991 samples, CTL-acetate was significantly weaker than XYZ-acetate. However, in the November 5, 1991 samples, no significant differences were noted in either comparisons.

Cotton

On March 30, 1991, CTL-cotton was significantly stronger than XYZ-cotton. EXP-cotton was significantly

weaker than both CTL and XYZ.

On November 5, 1991, EXP-cotton was significantly weaker than XYZ-cotton. No CTL-cotton was recovered.

EXP-cotton was significantly weaker than CTL-cotton on January 25, 1991, but not again until March 30, 1991.

Silk

EXP-silk was significantly weaker than XYZ-silk in March 30, 1991 and November 5, 1991 samples. CTL-silk was significantly weaker than EXP-silk in the March 14, 1991 and November 5, 1991 samples, and significantly weaker than the XYZ-silk in all samples collected February 10, 1991 through November 5, 1991.

Wool

EXP-wool was significantly weaker than XYZ-wool in February 10, 1991 and November 5, 1991 samples. No CTL-wool was recovered after March 30, 1991. There were no other significant differences.

Acrylic

No significant differences in breaking strengths were seen between XYZ-acrylic and EXP-acrylic. CTL-acrylic was significantly weaker than XYZ-acrylic in the November 5, 1991 sample. EXP-acrylic was significantly weaker than CTL-acrylic in the February 10, 1991 sample only.

CHAPTER V

DISCUSSION

HUMAN DECOMPOSITION

In winter conditions in East Tennessee, a single layer of clothing appears to accelerate human decomposition. Based on observations of insect activity and behavior, particularly the period from February 25 to March 30 (see Figure 6), the garment seems to have sheltered eggs and developing maggots direct from sunlight, rain, wind, and cold temperatures. Because it prevented a portion of the body fluids from seeping away, it helped to hold in moisture, creating a humid environment. Because fabric is a poor thermal conductor, the garment may have helped to conserve some of the heat generated by decomposition and the metabolic activity of the maggot mass. This combination of events helped to firmly establish the maggots even during colder months, while those on CTL could not.

The clothing also appears to have fostered a pattern of decomposition somewhat different from what is usually found. Most of the insect activity on EXP was concentrated initially in the urogenital area, with little or no activity around the face. This was probably due to a combination of the factors: the protection offered by the garment in the urogenital area, and the molds and fungus which were already well established around the face, thus discourageing the insect activity.

The substance which collected in the bottom of the garment was most likely a combination of the by-products of insect digestion and metabolism, and decompositional byproducts. The garment kept much of the body fluids from seeping away, resulting in a buildup of such wastes in and around the garment. To date, there has been no mention of such buildup in the literature.

This substance is obviously persistent. Its presence was noted in early May, and it was still relatively abundant in late September. Insect activity was still present in this substance in September. Since the body was skeletonized by this time, the deterioration rate of this substance when associated with skeletal remains, and the attendent entomology, might be another way of estimating interval since death.

GARMENT DETERIORATION

Aside from some fading of the color, the polypropylene showed no signs of deterioration. The cotton showed evidence of rotting and extensive mildew. By the end of the experiment it was fragile, and in places fragmentary.

YARN DETERIORATION

Visually and microscopically, there appeared to be little in the way of structural damages to the yarns and fibers used in the study. Most of the gross changes (discoloration, loss of luster, etc.), were due to various adherents rather than any apparent chemical damage. This is not unexpected -- Morse and Dailey and Morse et. al.

found that most common materials require at least a year to show any significant changes.

The breaking strength tests include some ambiguous results; there are instances where experimental samples are significantly stronger than XYZ-yarns, rather than the other way around, or where a sample was significantly stronger/weaker in the middle of sampling but not at the beginning or end.

These ambiguous results are probably due to a combination of factors. First, sample sizes were very small, perhaps resulting in unacceptable sampling errors. Second, most of the yarns being used were spun from staple fibers. These are short fibers which during spinning twist around one another. When running a breaking strength test, force is applied at each end of the yarn to pull the yarn apart. The yarns come apart one of two ways: either the fibers break, requiring more force, or the staple fibers slide apart from one another, requiring less force. Many of the samples tested had been soaked with rain and/or body fluids, and caked with dirt, mulch, dead skin, etc. The adherents can act as a sort of glue, holding the staple fibers together. When breaking strength tests are run on them, they may be more difficult to break not because they are stronger but because the by-products of the experiment are artificially binding the fibers more tightly.

However, in most of the breaking strength tests, there was evidence of weaker breaking strengths in both EXP-yarns

and CTL-yarns. These results dovetail well with certain other observations. Starting with March 30, 1991 EXP-samples, yarns were becoming greasy to the touch, due to exposure to fatty and oily by-products of human decomposition. The fats and oils acted as a lubricant which allowed the staple fibers in the yarns to be pulled easily apart. And while this does not point to actual mechanical weakness of the yarns, it does produce breaking strength differences which are statistically significant, and can therefore be expected in other tests and forensic cases.

Also, the weaker breaking strengths toward the end of the experiment fall into the ranges associated with deterioration due to exposure to sunlight (pers. comm. R. Bressee, Ph.D., January 1992). Although CTL-yarns were placed in shady locations, and EXP-yarns were inside the garment, they both apparently received enough sunlight to result in some destructive effects.

Nylon and polyester were not recovered from EXP on November 5, 1991. However, they were attached to the cotton side of the garment. By November, the cotton was very fragile and was embedded in the leaf mulch and decomposition products in the bottom of the garment. Recovery was very difficult for yarns attached to the cotton side, and therefore it is felt that the polyester and nylon did not deteriorate completely, but instead were simply not found.

Cotton and wool were not recovered from the CTL samples in November. No traces of them were found attached to the cord securing the CTL-yarn samples around the base of the tree to which they were anchored; nor were any traces found in the leaf clutter surrounding the samples. It is possible that enough deterioration occurred to permit the wool and cotton to detach from the cord and be washed away from the immediate area by rain and wind. Because cotton and wool were weaker in association with EXP than apart from EXP, it is felt that that would be more likely than for CTL-cotton and CTL-wool to completely deteriorate by November while EXP-cotton and EXP-wool were still recovered at that time.

CHAPTER VI

CONCLUSIONS

HUMAN DECOMPOSITION

A single layer of clothing appears to accelerate human decomposition. In this study, EXP showed signs of well established bloating after two weeks, with noticeable skin slippage and skin discoloration and the beginning of loss of head and body hair. Actual inflation began at about 41 days, or almost six weeks. CTL, however, required a month or more (at least twice as long as EXP) to reach well established bloating, and at least 10 weeks to reach inflation.

Insect activity on EXP was continuous from January 18, 1991 and well established after two weeks, while that associated with CTL was tenuous until the middle of March, two months later.

Using this study as a guideline an individual in shirt and pants in late winter/early spring conditions would reach the first stages of bloating in about two weeks, initial inflation in six weeks, active decay in approximately eight to ten weeks, and dry stage (with exposed bones and most soft tissues gone) at about fourteen weeks (or three and a half months). Maggot masses would be well established at about four to six weeks.

YARN DETERIORATION

The yarns in this study were less affected by decomposition than expected. However, tentative results

indicate that: cotton, wool and acetate deteriorate quicker wwhen exposed to environmental conditions including human decomposition than to environmental conditions and no human decomposition; silk, acrylic and nylon deteriorate more slowly when exposed to environmental conditions including human decomposition; and polyester showed no differential response.

A great deal of work still needs to be done in this area. Comparisons between clothed and nude individuals need to be made in all seasons and with more subjects. Examinations of the affect of human decomposition on common fabrics also need to be studied with larger sample sizes and for longer periods of time.

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